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ECOLOGICAL SURVEY OF THE JAMES RIVER IN THE VICINITY OF RIVERVILLE, VIRGINIA

By

RICHARD S. HERD

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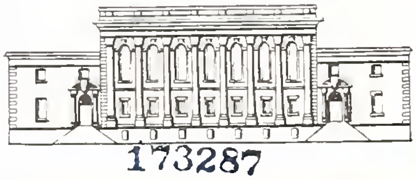

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Ecological Survey of the James River
in the Vicinity of Riverville, Virginia
(pre-discharge report)

April 1976

by

Richard S. Herd

Environmental Studies Program
Sweet Briar College

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ABSTRACT

An ecological survey of the James River is being conducted by Sweet Briar College to determine the impact of the Virginia Fibre Corporation (VFC) waste discharge upon this aquatic system. This report contains the pre-discharge assessment of the river and will be the base with which we will compare the ecological condition of the James after it has received the VFC waste discharge. The study area includes six sampling stations located on the James River from Riverville, Virginia downstream to Wingina, Virginia (approximately 20 river miles).

A comprehensive chemical and biological sampling program began in January, 1974. Eighteen physical and chemical parameters were measured weekly and intensive macroinvertebrate sampling was done throughout the year. We also attempted to relate the chemical and physical properties of this section of the James to its community structure.

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PREFACE

This research effort is sponsored jointly by Sweet Briar College (SBC) and Virginia Fibre Corporation (VFC), a corrugated paperboard manufacturer located on the James River at Riverville, Virginia. The purpose of that part of the study reported here is to establish the ecological condition of the James River in the 20-mile stretch downstream of the plant before any wastes are discharged by VFC. The 18 months of baseline data will be used later to assess the impact of the VFC discharge upon the aquatic ecosystem of the James by comparison with post-discharge conditions. Pre-discharge studies such as this investigation are unique and comparisons made by this method are probably more reliable than the more common upstream-downstream approach.

Sweet Briar College has undertaken this research project as an educational exercise in applied environmental research. Student assistants work in chemical and biological analyses in both the field and laboratory.

INTRODUCTION

According to publications of the Virginia Division of Water Resources (1969, 1970), the James River Basin extends for about 368 km (230 mi) through the center of Virginia. It varies in width from 16 to 144 km and includes a drainage area of 16,163 sq km (10,102 sq mi), about 25% of the total land area in the state. The James transverses four major physiographic provinces as it flows from west to east across Virginia. These are the Ridge and valley, Blue Ridge, Piedmont, and Coastal Plain provinces.

Despite the relatively short length of the Basin, climatic conditions vary considerably. Mountainous regions at the Western extreme have considerably more fluctuation in temperature and precipitation than does the coastal plain. Average annual temperature in the Basin ranges from 12C in the mountains to 15C near the Coast; average annual precipitation throughout the Basin is about 107 cm (42 in).

Although more than two million people live in the Basin, it is essentially rural in character. Population is concentrated in the metropolitan areas of Lynchburg, Richmond and Newport News. Much of the income in the basin is derived from farming and forestry, but, a substantial part of the economy results from manufacturing. Recreation is of considerable economic importance in the James River drainage area.

The James River from its formation at the junction of the Jackson and Cowpasture Rivers in western Virginia (el 328M above mean sea level) to its mouth at Hampton Roads is 536 km long; the lower 168 km of the stream are tidal.

The Piedmont Section of the river, 368 km above the fall line, has an average gradient of about 1.5 m/km and is subject to extreme fluctuation in flow, dependent upon rainfall in its upper reaches and releases from peaking power dams. The exposed bedrock and boulder in the Piedmont section, along with the absence of a deep channel, renders the river non-navigable from the fall line to its origin. Much of the river is comparatively free of industrial and domestic pollution although certain points, e.g., Covington, Big Island, Lynchburg, Richmond, Hopewell and Hampton Roads discharge considerable organic and inorganic wastes.

The Piedmont section of the James River, the focus of this investigation, has been studied less and is the least understood of the river physiographic provinces (Woolcott, 1974). The relatively difficult collecting conditions which the river presents in this region and the assumption by naturalists that the region did not offer as interesting a variety of organisms as were to be found in the mountainous and Coastal Plain areas have been responsible in part for the paucity of biological data from this section of the river (Raney, 1950).

Prior to the work of Dahlberg (1972), Woolcott (1974) and their co-workers, very little ecological information existed for the Piedmont section of the James River. Parker and Knapp (1966) intensively monitored the water quality of the James River for one week at both Riverville and Allens Creek, Virginia. They found overall water quality to be good. The past ten years have shown increases in DO concentration and a decrease in color concentration at both stations.

Labuy (1967, 1968), using macrobenthic organisms as indicators of water quality, determined the James River had recovered from the waste-loading of Lynchburg by Riverville, at which point community diversity increased markedly, indicating good water quality. Unfortunately, no data are available below this point on the James to the Bremo Bluff area. Besides the above investigations, pertinent data are available also from the files of the State Water Control Board (Water Quality Surveillance Network). Since 1968, Virginia Water Quality Monitoring records have indicated that water quality downstream from Lynchburg at Bent Creek (003) has contravened stream standards on five occasions.

Information on physical, chemical economic and social characteristics of the Piedmont Province is included in a four-volume series of James River Basin Planning Bulletin published by the Virginia Division of Water Resources (1969, 1970 a & b and 1971) and in a publication edited by Millar et.al. (1971). An addendum to the Bulletin, emphasizing economics and water quality was released by the Virginia State Water Control Board (1972). Water Quality records for the James Basin are provided by the U. S. Geological Survey (1973). Climatological data summaries for certain stations in the Piedmont Province are presented by Crockett (1972). The James River Basin (Virginia Academy of Science, 1950) is a compilation of papers by different authors dealing with various biological, physical, economic and sociological aspects of the Basin. Many of the papers in the book are general in both subject and geographical location, but the paper on fishes by Raney (1950) is especially applicable to the Piedmont section of the river.

Reports of studies of invertebrates from the Piedmont section of the James are particularly sparse. Studies of crayfish in the James River were made by Smart (1962) and James (1966). Peters (1974) described the ostracods in the York and James Rivers. Falls (1974) surveyed the freshwater oligochaetes in the Richmond area. Pugh (1956) reported on the mayfly larvae in a Virginia Piedmont tributary. Bishop, et.al. (1973) and Bishop (1973) presented papers at state and regional professional meetings on the invertebrate fauna of the James at Bremo Bluff.

The Piedmont section of the James River is approximately 240 km long, its general direction of flow is east. Near Lynchburg it abruptly turns to the northeast following a fault line of precambrian rocks (Fenneman, 1938) for about 64 km before reestablishing a southeastward direction near Scottsville. Except for Lynchburg in the west and Richmond on the Fall Line, the river is bordered through this stretch by farmland and small villages but may become urbanized through the development of industrial sites and recreational facilities (Holm, 1968).

In October of 1973 a research program was initiated to establish baseline data on the biology and chemistry of that part of the James River that would be influenced by the VFC discharge. This report summarizes that effort and will be used as a basis for comparing data gathered post-discharge from the same area.

More commonly such studies are initiated after discharge into the receiving stream has already commensed so that no genuine baselines are possible.

We view the river as a system with living and non-living components all of which interact. The system changes as it moves through space and

endures through time. Our sampling program was designed to deal with the system in its several parts as well as the sum, and to take account of the systems changes through time and space.

Six sampling stations were located at approximately equal intervals within the 32 km study segment. An intensive investigation of the Macroinvertebrate community was undertaken in an effort to establish the structure of this important trophic level before VFC's waste discharge began. A species list and estimates of relative biomass of the fish population was compiled during the summers of 1974 and 1975. Estimates were made of the primary production during low flow periods by use of in-situ continuous monitors and digitized recording equipment. Water samples were taken on a weekly basis and analyzed for 18 physical and chemical parameters which might be influenced by a pulp mill's wastes.

The VFC plant is located approximately 40 km below Lynchburg on a segment of river for which little ecological information was available, but whose water was clean by present standards. As industrial and residential development has been forecast for this region, it seems important that we obtain and place in record as comprehensive an array of information as our resources permit. In addition it was in VFC's interests to establish as irreproachable a baseline as possible before other facilities could begin to discharge wastes into the river and thereby create potential synergistic effects or at least confound the question of responsibility.

We would prefer to have had two full years of data prior to the first waste release, but several months were spent negotiating, staffing, planning and becoming equipped. As it is, the eighteen-months baseline we are

reporting here is rather unique in the annals of environmental impact studies. That the pre-discharge study was launched at all must be attributed to the foresight of the officers of the Virginia Fibre Corporation, who saw with unusual clarity a beneficial conjunction of their own and the public interest.

STUDY AREA DESCRIPTION

The study area lies entirely within the Piedmont Province which is bordered on the west by the Blue Ridge and on the east by the Coastal Plain Province. The immediate drainage basin consists of gently rolling terrain with broad, flat-topped hills and narrow valleys. The entire province exhibits a slight south-eastward slope from an altitude of approximately 300 m (1,000 ft) at the western margin to 60 m (200 ft) at the eastern margin.

The stream bed profile of the Piedmont Province falls approximately 1.5 m/km. The James River at Bent Creek (station 003) drains approximately 5,855 km^2. The critical low flow of the James at Bent Creek is 137 m^3/sec (450 cfs). The 20 year mean flow at Bent Creek is 222m^3/sec. (Virginia Division of Water Resources, 1969). Flow speed varies with discharge but generally averages approximately 0.25 - 0.5 m /sec in most areas.

The James throughout this section has been classified by the State Water Control Board as class III A waters, suitable for public water supply and fish propagation but not recommended for direct contact or ingestion by humans or livestock. Bass, sunfish and catfish are plentiful in the James from Riverville downstream affording some of the finest fishing water in central Virginia.

Surface water is a solution of gases, liquids and solids characterized by the atmospheric composition and the geo-chemical nature of the watershed through which the river courses. The Piedmont Province is a matured, dissected upland underlain by a vast complex of igneous metamorphic and sedimentary rocks of precambrian and cambrian age. Defor-

mation and the intrusion of igneous materials have altered pre-existing sedimentary rocks of the Piedmont Province into metamorphic rocks which include gneisses, schists, marbles and quartzites (Virginia Division of Water Resources, 1970).

The James River receives its major waste loading at Lynchburg, the only large (metropolitan area population about 75,000) city on this stretch of the river. Organic wastes from pulp and paper production along with municipal wastes constitute the major point sources of oxygen-demanding materials discharged to the James above this study area (Table 1). Total BOD loading on this section of river is approximately 22 x 10^3 kg/day. The Tye River contributes another 150 kg/day, (Virginia Division of Water Resources, 1969). The water quality of the James has recovered significantly by the time it reaches Riverville. There is no point-source of organic matter within the study segment.

The study area extends from a point 1.6 km above the VFC discharge to a point 32.0 km (20 mi) downstream. This section of the river forms the boundary between Amherst and Nelson Counties on the north and Appomattox and Buckingham Counties on the south side of the river. The study area was extended downstream as far as Wingina to assess the effects of the Tye River tributary upon the James.

The river through this section is 150-250 M in width. The substrate is composed principally of bedrock which has been twisted and folded into numerous synclines and anticlines. The bottom ranges from silt through sand, gravel, cobble and bedrock and much of the bottom is overgrown with a thin ($\leq$5 mm) periphyton of mixed chlorophytes, cyanophytes and diatoms.

TABLE 1.

Major point sources of pollution (100 lbs BOD_5/day) that discharge into tributaries and main stream of the James River in the upper Piedmont Province.

Source*	Receiving Stream	Total BOD (lbs/day)	kg/day
Owens Illinois Company	James River	16,111	7,308
Lynchburg Foundry (Lynchburg)	James River	121	55
Glamorgan Pipe and Foundry	James River	895	406
Madison Heights, Virginia	James River	240	109
Lynchburg, Virginia	James River	5,650	2,663
Lynchburg Training School	James River	490	222
Mead Corporation	James River	26,000	11,793
Kavanaugh Industries	James River	55	25
Lynchburg Foundry (Mount Athos)	James River	345	156

*The major industrial discharges to the James River in the upper Piedmont originate from pulp and paper, primary metals fabrication and a nuclear material plant.

The James takes a northeast direction at Lynchburg following the James River synclenorium. These rocks have been divided into the Candler, Arch Marble and Mount Athos formations. The Candler Formation is chiefly composed of grey to green phyllites, metagraywackes and schists. The Arch Marble is a fine-grained, highly impure marble with a distinctive blue color. The Mount Athos Formation consists mainly of quartzites and white marble (Virginia Division of Water Resources).

Pools and riffles are well developed. Riffles are formed of exposed bedrock, rock and rubble. Pools contain deposits of gravel sand and silt and waterlogged tree trunks, and organic detritus are abundant. Mud, sand and organic detritus compose the river banks in most places. The river flow is moderate to fast except where fallen debris or small islands create areas of quiet water. The river falls at the rate of approximately 0.85 m/km through the study area from an elevation of 137 m at Riverville to 110 m at Wingina. Average annual precipitation is 108 cm (Virginia Division of Water Resources, 1970).

The river through this section appears to be relatively unpolluted. It is bordered by woods and farmland and is influenced little by urban areas. Sewage and industrial waste from the city of Lynchburg, 40 km above Riverville undergoes natural purification processes before it reaches the study area. Some streams flow into the James through the study area. Wreck Island creek enters the James at Riverville just below station 002 (river mile 228). Bent Creek joins the James at river mile 231.0. David Creek enters the James at river mile 232.3, one mile below station 003. The Tye River enters the James at Norwood, immediately below

station 005 (river mile 240) (Figure 1). None of these tributaries contributes an appreciable amount of industrial or domestic wasteload.

Throughout the study area vegetation overhangs the banks. There is considerable leaf fall from deciduous trees during the fall, winter and early spring resulting in a substantial amount of organic detritus along the banks and in back water areas. This allochthonous material makes a significant contribution to the energy budget of this river. The annual leaf fall of deciduous shrubs and trees is known to contribute stignificantly to trophic structure and dissolved nutrients in a stream (Fisher & Likens, 1973). The dominant vegetation along the banks in order of abundance is *Celtis occidentalis* (hackberry), *Platanus occidentalis* (sycamore) and *Acer rubrum* (red maple). Scattered specimens of *Fraxinus sp.* (ash) were present. *Betula nigra* (river bush) and *Salex sp.* (willow) also occurs intermittently. *Rhus radicaus* (poison ivy), *Catystigia sp.* (bendweed), *Impatiens sp.* (waterweed) and *Passflora sp.* (passion flower) are dominant herbs. The only aquatic macrophyte found growing in the shallows was *Justica americana* (water willow). Open pasturelands and cultured fields are located behind the line of trees along the shore on both sides of the river, but many stretches of the river are paralleled by steeply sloping banks and hills.

Our sampling design was based upon the need to compare ecologically similar stretches of river above and below VFC's discharge point. Because a receiving stream tends toward recovery through natural processes as it flows along, we also tried to balance the first requirement of ecological compatibility against state and federal agency requirements as well as the existance of geographic features downstream.

Collections were made within the study area at specified locations designated as stations. Each station included approximately 300-500 m of shoreline. The factors considered in determining ecological similarity between stations were current, riverbed, morphology, depth, substrate, width, stability, sedimentation, the quality and quantity of debris and ease of access (Cairns, 1966).

The plan that resulted from these multiple considerations is shown in Figure 1. The mill discharge is located at river mile 227 (Lat. 37° 30'82''N, long. 78°58'80''W). Control station 001 is 1 km upstream and the first downstream station is 002, 305 m from the discharge. The next is 003, 7.25 km downstream at river mile 231.3 where U. S. Route 60 crosses the James. Continuing downstream, station 004 is at Greenway, 14.5 km from the discharge at river mile 235; station 005 is just upstream of the confluence of the Tye River, 22 km from the discharge at river mile 240; and station 006, the last, is at Wingina, the point where Route 56 crosses the James, 32 km from the point of discharge at river mile 245.

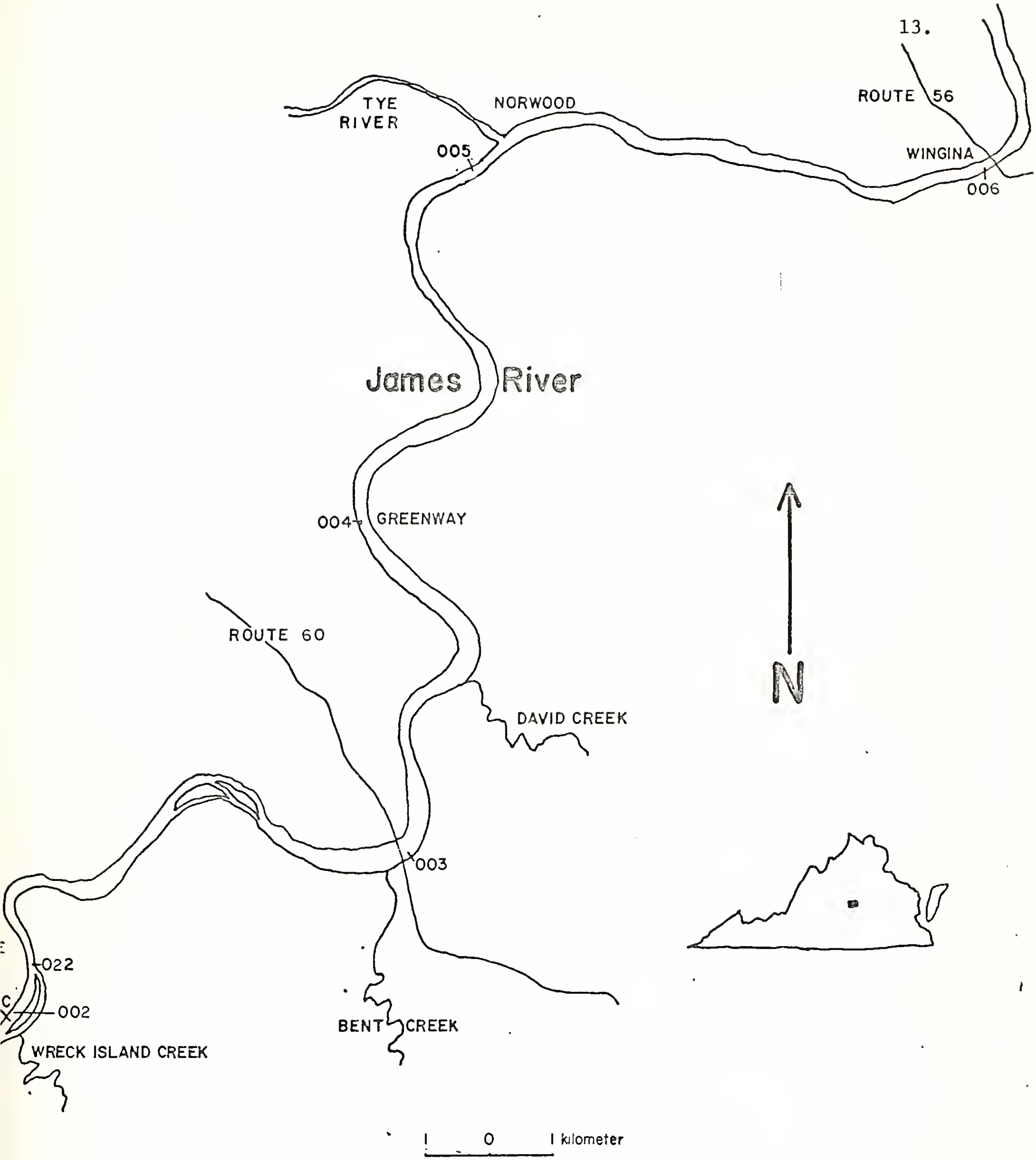

FIGURE 1.

Station location and major tributaries to the James River within the study area

PHYSICAL & CHEMICAL PROPERTIES

INTRODUCTION

The physical and chemical properties of an aquatic system determine the kinds and number of organisms that reside there. No survey would be complete without information on the physical and chemical properties of that system. Changes in the environment, either biotic or abiotic, to which organisms are adapted may bring about changes in community structure as populations favored by the new conditions increase in numbers and those for whom the conditions become less favorable, decrease or disappear. This study includes measurements of water quality parameters which we feel have a credible link to the biota and are likely to be influenced by the Virginia Fibre Corporation discharge.

The objectives are to establish baseline data on which to compare pre-discharge with post-discharge conditions and correlate these physical and chemical data to the structure of the biological community.

From the standpoint of water pollution, pulp and papermills are of great significance due to the rather large volume of water used in production. The principal problems associated with pulpmill wastes are toxicity, depressed DO's and slime growths. One seldom encounters cases of acute toxicity. More often, the problems are related to the sugars which cause high BOD's and allegedly provide nutrients that allow *Sphaerotilus* slime growth to flourish. Particulate matter, when not removed from the effluent, tends to settle out in slow waters and blanket the bottom smothering any benthic organisms. Color is also a problem characteristic of the pulp and paper industry; it has been most often

treated as an aesthetic problem, although it reduces light penetration into the water and thus may limit gross production.

A substantial portion of pulpmill wastes, including the toxic components, are very amenable to microbial degradation. Given sufficient time, the process of degradation of the toxic component of pulp wastes takes place.

Determining the toxicity of complex wastes from pulp mills presents a number of problems. For one thing, these wastes contain as many known and, perhaps, equally as many unknown toxic substances in small quantities. The toxicological and other physical and chemical characteristics can vary considerably during any given day, due to changes in process, sources of supplies, and other end products being produced. Considerable variation in effluent characteristics can occur even in a one-day period.

METHODS AND MATERIALS

Water was collected at the surface about 2 m from shore at each station. Ten parameters were measured weekly; alkalinity, color, dissolved oxygen (DO), biochemical oxygen demand (BOD), fecal coliform density, pH, specific conductance, turbidity, temperature and river discharge. Nine other factors were measured at least once a month and more frequently as time permitted. These were: chloride, sodium, solids (settleable, non-filterable and volatile), sulfates, total kjeldahl nitrogen (TKN), total phosphorous and chemical oxygen demand (COD). All analyses were made according to Standard Methods for the Examination of Water and Wastewater, 13th edition (SM, 13) or the U. S. Environmental Protection Agency's Methods for Chemical Analysis of Water and Wastes, 1971.

Dissolved oxygen measurements were made in the field with a YSI Model 54 DO meter, but replicate DO samples were also fixed in the field and returned to the laboratory for analysis by the alkaline iodide-azide modification of the Winkler method (±0.1 mg/1)(SM,13). The YSI instrument was used to determine DO in the BOD analyses. The hydrogen ion concentration and the specific conductance were also read in the field using the I.L. Model 175 porto-matic pH meter and the Beckman RB3 Solu Bridge respectively. Water temperature was measured with both the YSI DO meter and an ASTM stem thermometer to the nearest 0.1°C. Water for bacteriological analysis was taken in a sterilized 300 ml widemouth bottle. The remaining water was poured into one gallon plastic cubitainers, iced and returned to the laboratory for immediate analysis,

time permitting. Samples that could not be analyzed on the same day were preserved according to Standard Methods (1971).

Discharge of the James River throughout the study area was taken from the U.S.G.S. gauging station at Bent Creek, Virginia (station 003). The only major tributary within the study area is the Tye River which enters the James immediately downstream of station 005. Therefore, discharge was considered to be approximately the same at all stations except 006. Discharge correlations were only run on stations 001-005 since accurate discharge data for station 006 was not available.

All collected data was filed and stored on magnetic tape in a Honeywell 1640 computer. Statistical comparisoms of annual mean values for all stations were made using one way analysis of variance and Duncans Multiple Range test. The intensity of association between paired variables was measured by correlation analysis. Individual cases of correlation were carefully analyzed before inferences were drawn from them. A significance level of P=0.5 was established as a criterion for all comparisons and correlations.

RESULTS AND DISCUSSION

DISSOLVED OXYGEN

Dissolved oxygen (DO) is one of the most significant water quality parameters because it interacts so pervasively with other biological and chemical factors. Except where it is nearly always at saturation, DO can influence the distribution and physical condition of aquatic organisms. The amount of DO needed to support the balanced natural life in a river is dependent upon the kind of life that is present. In many streams, 3-5 mg/l of DO is considered the lowest limit that many forms of aquatic life can tolerate over an extended period of time. Over short periods, as little as 2 mg/l can be tolerated by some species. The effect of low DO condition is to eliminate many fish species, especially game fish and many kinds of insects. Hence community diversity is reduced.

The amount of oxygen that can be held in aqueous solution is determined by temperature, atmospheric pressure and the concentration of ionic species. With this saturation level as the upper limit, oxygen is removed from solution by biological respiration and biochemical oxidation. It is added to the water by adsorption from the atmosphere or photosynthesis, but the extent to which this latter process is effective is determined by the ratio of periphyton to the volume of water flowing over it. Oxygen absorption from the atmosphere is usually greatest when there is considerable turbulence and the water is much cooler than the atmosphere. Primary production also varies with temperature, turbidity of the water, solids load and solar radiation.

The Piedmont section of the James is sufficiently turbulent and shallow to permit constant mixing with the result that vertical stratification from top to bottom does not persist. Such waters, if unpolluted, vary between 75 and 150% of saturation and remain close to equilibrium with the partial pressure of oxygen in the air (Hynes, 1970). Slow streams having thick growths of rooted aquatics or heavy growths of periphyton, however, may reach 200% or more of saturation at midday when photosynthetic oxygen is produced faster than it can be diffused through the surface (Hynes, 1970).

Oxygen concentrations (as percent of saturation) showed considerable variation from station to station on the same sampling days, depending primarily upon net primary productivity. The majority (89%) of the samples showed oxygen saturation ratios of 85% or greater. Fifty-four percent of the samples were saturated or super saturated. The highest observed concentration was 149% of saturation at station 001 on 25 September 1974. The lowest was 73% at stations 001 and 004 16 October 1974.

Table 2 shows that the extremes of absolute oxygen concentration were 6.05 mg/l and 13.75 mg/l at station 005 and 001 respectively. The lower value was observed 9 July 1974, following a period of high water, and the higher was observed on 24 September 1974 following an extended period of low, less turbid water; both were recorded during daylight.

Because the conditions that favor oxygen solution vary so markedly in a stream from hour to hour or week, averages for a month or year may not be definitive. For this reason we present the data as it is shown in Figure 2. The mean $(\overline{X})$ concentration and the range are self-explanatory; the standard error of the mean $(Se\overline{X})$ is a statistical measure of

TABLE 2. EXTREMES OF PHYSICO-CHEMICAL CONDITIONS

PARAMETER	001	002	003	004	005	006
Temperature °C	3.50-30.50	3.40-29.50	3.40-29.50	3.50-29.00	3.50-28.25	2.80-27.50
Alkalinity (mg/1)	24.58-98.32	37.53-104.5	35.58-96.90	37.05-102.0	24.58-96.40	29.83-96.00
Chloride (mg/1)	2.52-28.95	2.52-30.20	1.26-30.20	2.52-32.72	1.26-31.56	1.26-22.65
Color (color units)	10.0-100.0	10.0-110.0	10.0-110.0	10.0-120.0	10.0-110.0	10.0-100.0
DO (mg/1)	6.55-13.75	6.75-13.24	6.70-13.64	7.00-13.56	6.05-13.45	6.40-13.34
BOD (mg/1)	.72-8.20	0.0-10.15	0.0-4.35	.73-5.08	.68-3.76	.55-10.15
FC /100 ml	10.0-5570.0	22.0-4170.0	16.0-3420.0	10.0-2700.0	3.00-3200.0	0.0-3340.0
pH	6.30-8.66	6.30-8.77	6.40-9.35	6.40-9.12	6.70-8.86	7.30-8.79
Sodium (mg/1)	4.40-19.50	2.00-20.50	3.60-22.30	1.50-23.0	1.40-21.0	2.30-12.70
Solids: Settleable (ml/1)	0.1-0.1	0.1-0.1	0.1-0.15	0.1-0.22	0.1-0.2	0.1-7.0
non-Filterable (ml/1)	4.80-45.80	4.10-56.20	5.80-70.60	5.20-48.80	5.60-48.40	4.80-208.8
Volatile (mg/1)	2.00-8.80	2.10-10.80	2.10-11.80	1.60-18.80	2.60-21.20	2.20-22.80
SC (units/cm^3)	72.0-375.0	110.0-365.0	100.0-360.0	105.0-360.0	110.0-360.0	105.0-330.0
Sulfates (mg/1)	10.0-31.0	8.0-31.00	9.0-29.50	8.0-21.80	8.0-29.30	8.0-31.80
TKN (mg/1)	.01-9.60	.01-17.08	.01-14.06	.01-12.38	.01-22.12	.01-14.28
Total Phosphorous (mg/1)	.018-.310	.01-.268	.01-.386	.015-.260	.010-.176	.018-.394
Turbidity (ftu)	1.80-150.0	2.0-165.0	2.0-155.0	2.20-190.0	2.10-255.0	2.20-325.0
COD (mg/1)	7.76-23.44	10.43-30.40	1.74-20.14	3.39-21.71	3.56-23.74	0.0-26.16
Flow (m^3/sec)			24-2105			

dispersion, that is, the relative number of observations that are close to or dispersed from the mean. A large Se$\overline{X}$ indicates great variability in observed values. Dissolved oxygen means as used here are representative of conditions only at the time of sampling. Mean saturation values for all stations were not significantly different at the P=.05 level. Mean percent saturation values at stations 005 and 006 were slightly lower than the other stations (Figure 2). This variation occurred because the downstream stations were sampled more often before noon than the others and not because of organic loading. By lumping oxygen saturation values at all stations for all sampling dates together we can eliminate the time-of-sampling variable and calculate a mean of 99.5% of saturation for *all* DO samples. Mean concentrations as high as those in Table 3 (Appendix A) indicate a very productive river with little organic loading (see productivity and BOD sections).

In any case, there was no significant difference among the six stations and oxygen concentrations were never observed to be less than the 5 mg/1 daily mean set by the Virginia SWCB as a criterion for class III A waters.

The seasonal variation in oxygen concentration is shown in Figure 4 as absolute values (mg/1) for nearly all of 1974 and seven months of 1975. At first glance there might appear to be a difference between the two years and for this reason we represent the same observations in Figure 5 as percent saturation. Just as DO concentrations were higher in 1975 for the same month, so temperatures were lower. A significant, positive correlation (P=.01) also existed between DO and stream discharge, probably

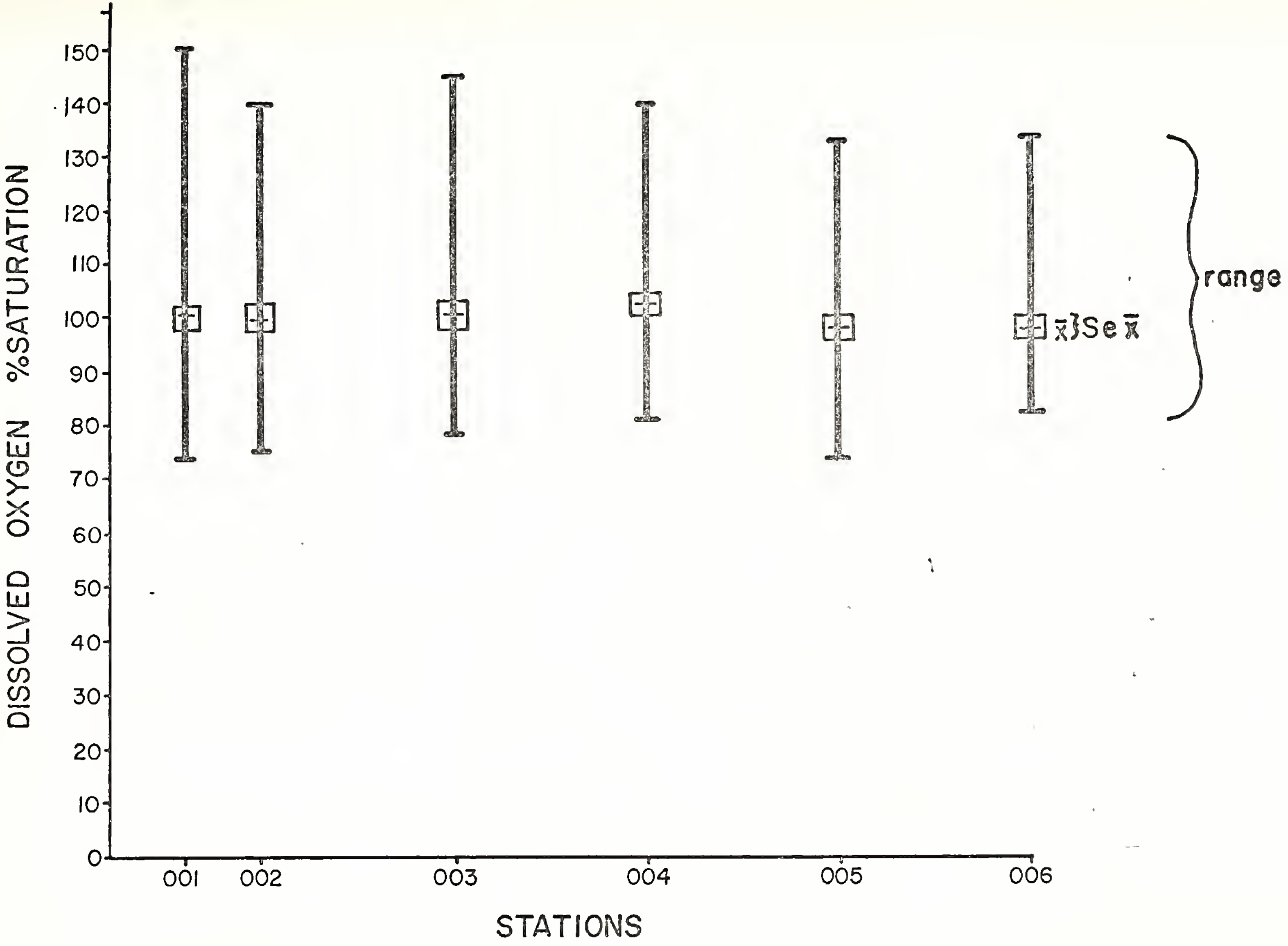

FIGURE 2.

Mean, range and standard error of the mean (S≋ $\overline{X}$) the DO percent saturation at each station.

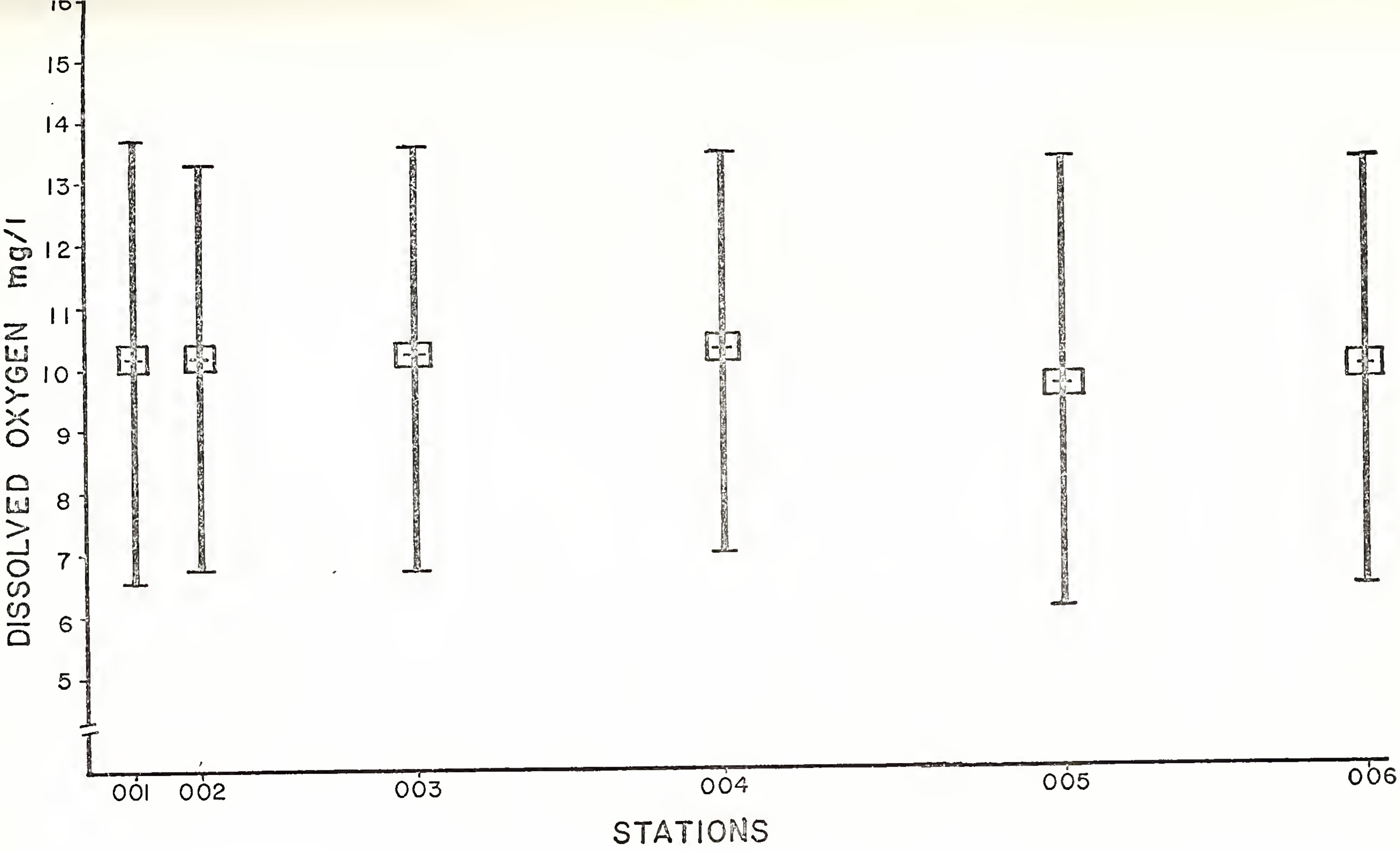

FIGURE 3. Range, mean and standard error of the mean of dissolved oxygen concentration at each station (pre-discharge).

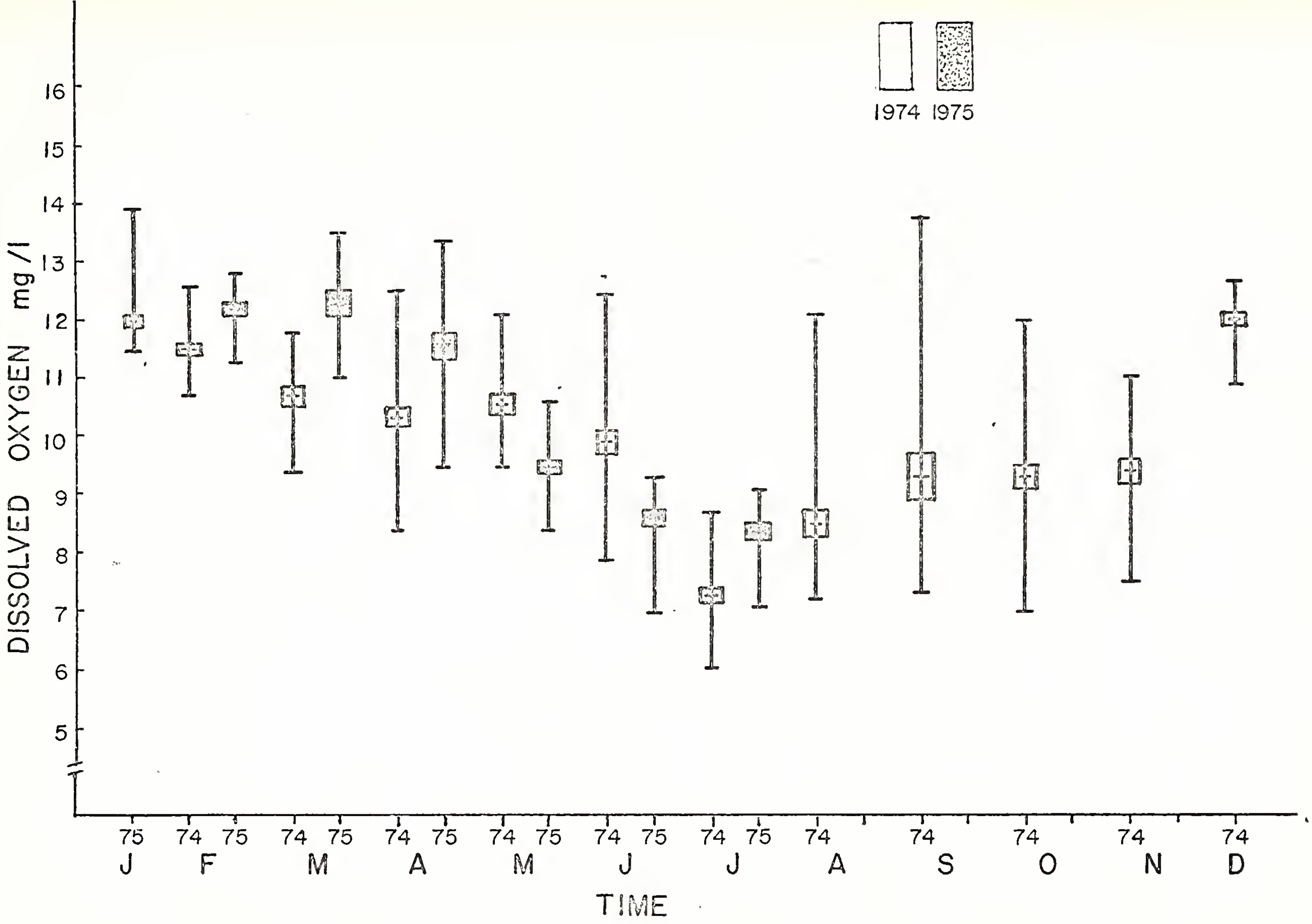

FIGURE 4. Seasonal range, mean and std. error of the mean for the DO concentration within the study area (pre-discharge).

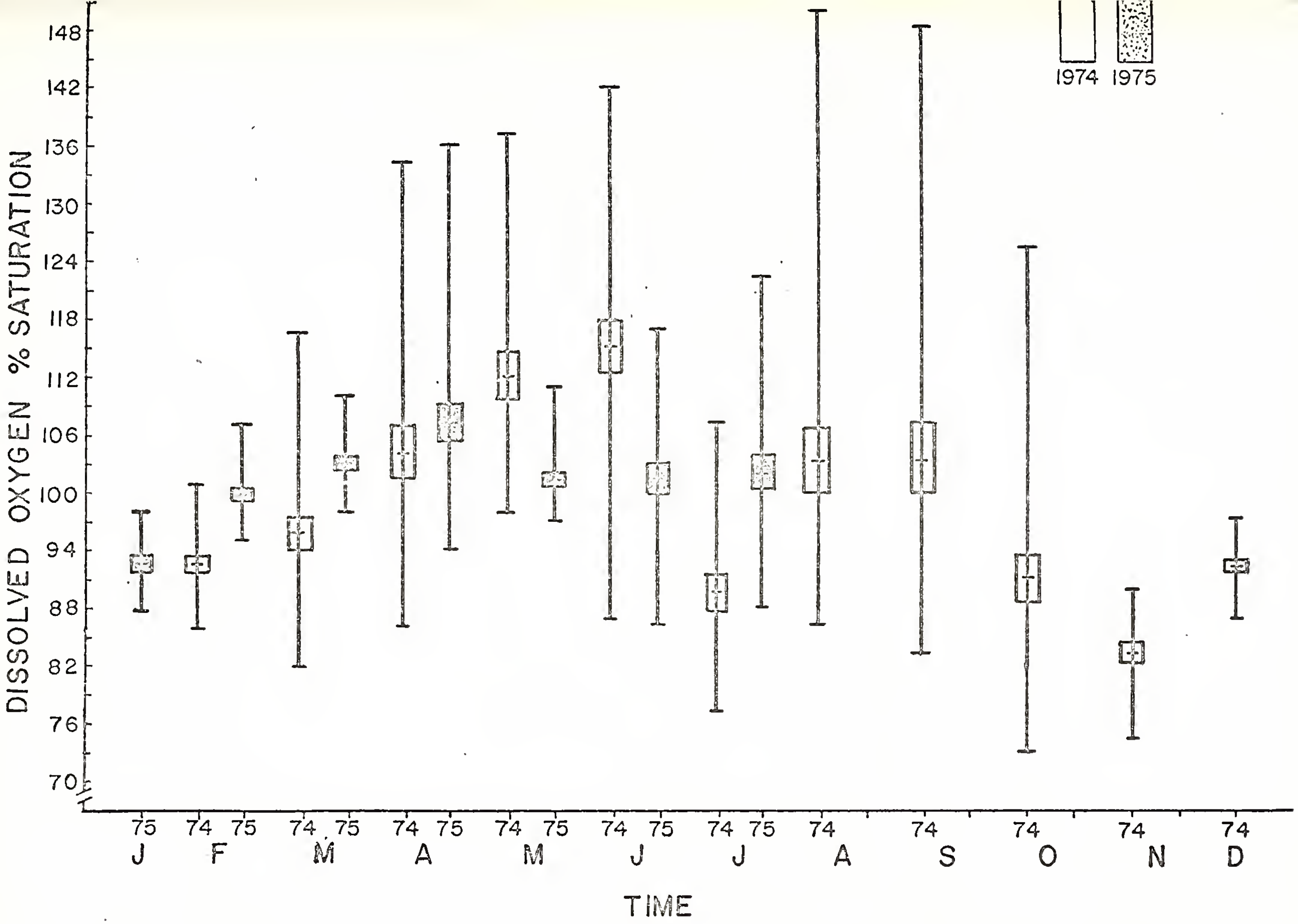

FIGURE 5. Seasonal range, mean and std. error of the mean of DO percent saturation within the study area (pre-discharge).

a result of the increased reaeration capacity of the river. DO concentration was negatively correlated with volatile solids significant at the P=.01 level but could not be negatively correlated with BOD. DO concentration, however, was negatively correlated to pH and alkalinity (significant at P=.01) indicating that net primary production contributes a significant portion of the DO in the river. It appears that the DO concentration in this section of the James is more closely associated with temperature, river discharge and primary production than with organic loading (e.g., respiration).

DO was negatively correlated to color, turbidity and solids load, significant at the P=.05 level. These conditions diminished light penetration limiting productivity. Turbidity and solids have a scouring effect on the periphyton thus reducing photosynthesis.

It is interesting to note that DO could be significantly associated with more water quality factors than any other variable we measured, an indication of its importance in the aquatic ecosystem. Mean DO concentrations are comparable at each station indicating no appreciable organic loading immediately above or within the study segment. We can conclude that the dissolved oxygen level in this section of the James denotes a healthy ecosystem capable of supporting a diverse and dense fauna.

TEMPERATURE

Temperature is a prime regulator of natural processes; for every 10°C (18°F) increase in temperature, chemical reaction rates are approximately doubled. Water temperature has many direct and indirect effects on aquatic life. Since most aquatic organisms are poikilothermic, natural temperature patterns influence all phases of their life histories and activities, such as feeding, growth, sexual maturation and migration. The relationships of temperature and aquatic life have been well studied. Extensive bibliographies and detailed surveys of the subject have been published by the American Society of Civil Engineers (1967), Brett (1960), Mirhusky and Kennedy (1967), Raney (1967) and Wurtz and Renn (1965).

Virginia Fibre Corporation is not expected to have any measurable effect upon the natural temperature of the James as their effluent will pass through a seven-day holding pond. It is important however, to know the natural temperature of the water in order to understand community structure and function.

Although the mean temperature at station 006 was slightly lower than the others (Figure 6) due to the influence of the Tye River, it did not differ significantly according to analysis of variance (P=.05). Variation in temperature between stations on the same sampling day was dependent upon the time of day the sampling was taken and whether it was taken in a pool or a riffle area.

Figure 6 shows the temperature range, mean and standard error of the mean for each station on all sampling dates. Figure 7 represents the monthly mean temperature, range and seasonal trend for all stations in the study area. The highest recorded temperature was 30.5°C at station 001 on

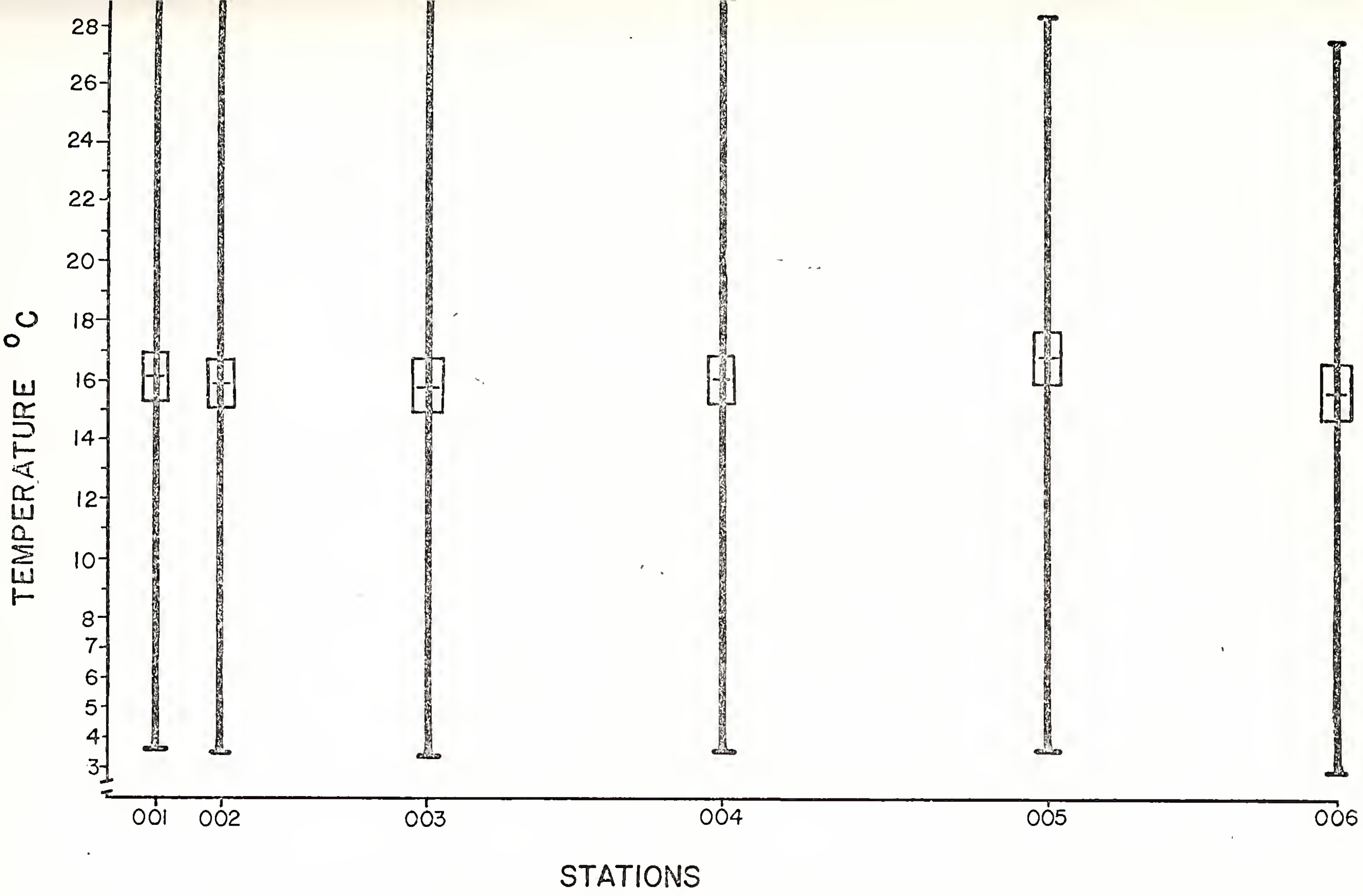

FIGURE 6. Range, mean and standard error of the mean of water temperature at all stations (pre-discharge).

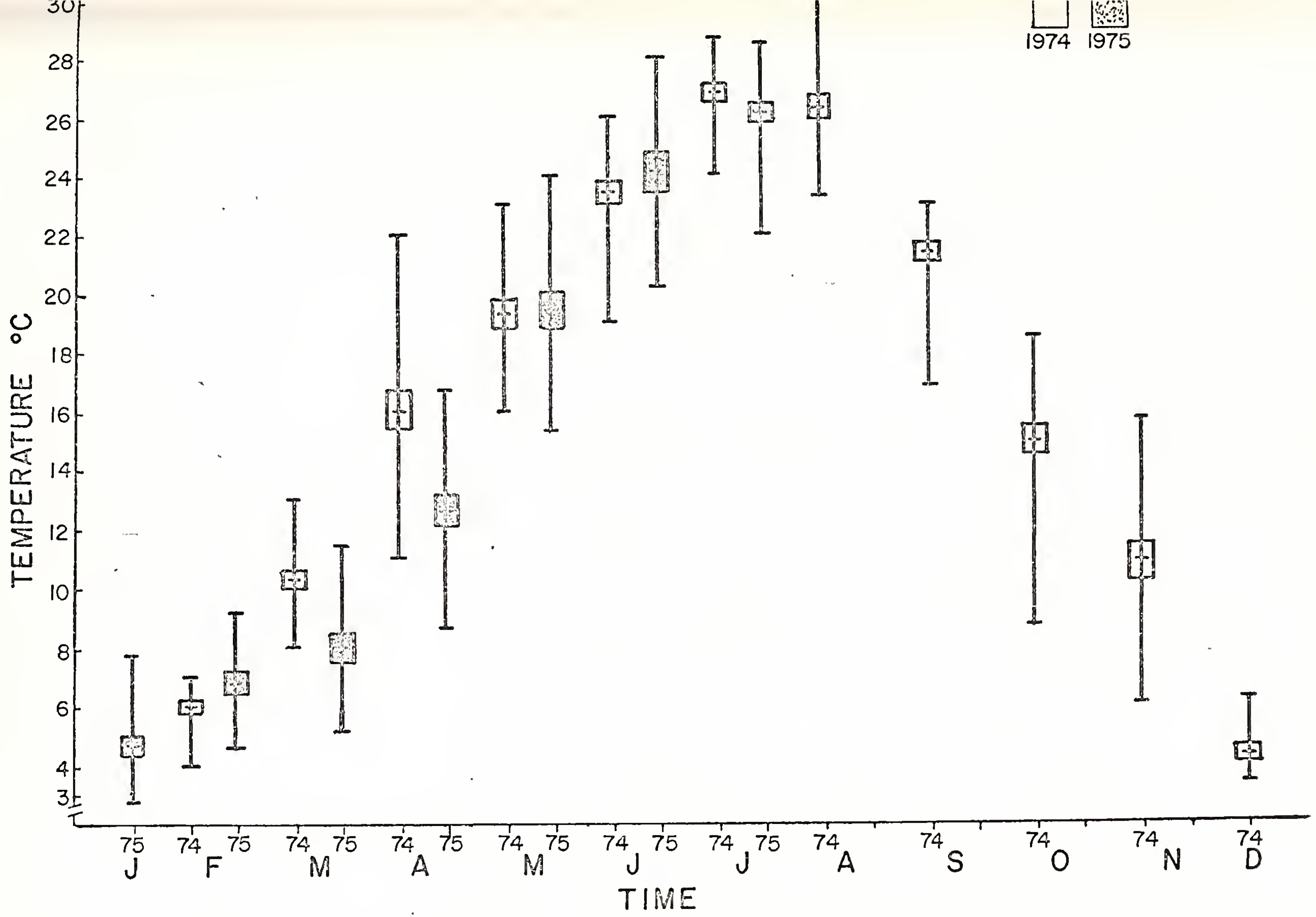

FIGURE 7. Seasonal range, mean and standard error of the mean of water temperature within the study area (pre-discharge).

29 August 1974. The lowest recorded temperature was 3.0°C recorded at station 006 on 15 January 1975. (Table 2).

RIVER DISCHARGE

Since organisms and the concentration of chemicals in streams -- including dissolved oxygen -- depend to a great extent on flow rate, the measurement of river flow is an important part of any river survey. The speed of water movement is extremely important to aquatic organisms in a number of ways including the transport of nutrients and organic food past those that live on stationary surfaces; the transport of plankton and drifting benthos which in turn serve as food for higher animals; and the addition of oxygen to the water through surface aeration. Flow determines those species of macroinvertebrates that may be present in a particular stream reach. Some require fast water for development whereas others flourish best in sluggish water.

River discharge must be considered when measuring the concentration of chemical components of the system. High discharges dilute the pollutants whereas low discharges concentrate the constituents. All measured parameters except total phosphorus showed a significant correlation with discharge. Discharge was correlated to measured concentrations at station 001-005 only. Station 006 was deleted because we did not have Tye River discharge. DO, BOD, turbidity, solids and the fecal coliform density are positively associated with discharge whereas total alkalinity, pH, sulfate, chloride, sodium, and color are negatively correlated.

High discharge generally occurs in late winter and spring in the James River as shown in Figure 8 which represents the mean monthly discharge at the U. S. G. S. gauge station, Bent Creek (station 003) on sample days. High flow carries a heavier sediment load and tends to scour streambeds of attached algae which thus alters the net primary

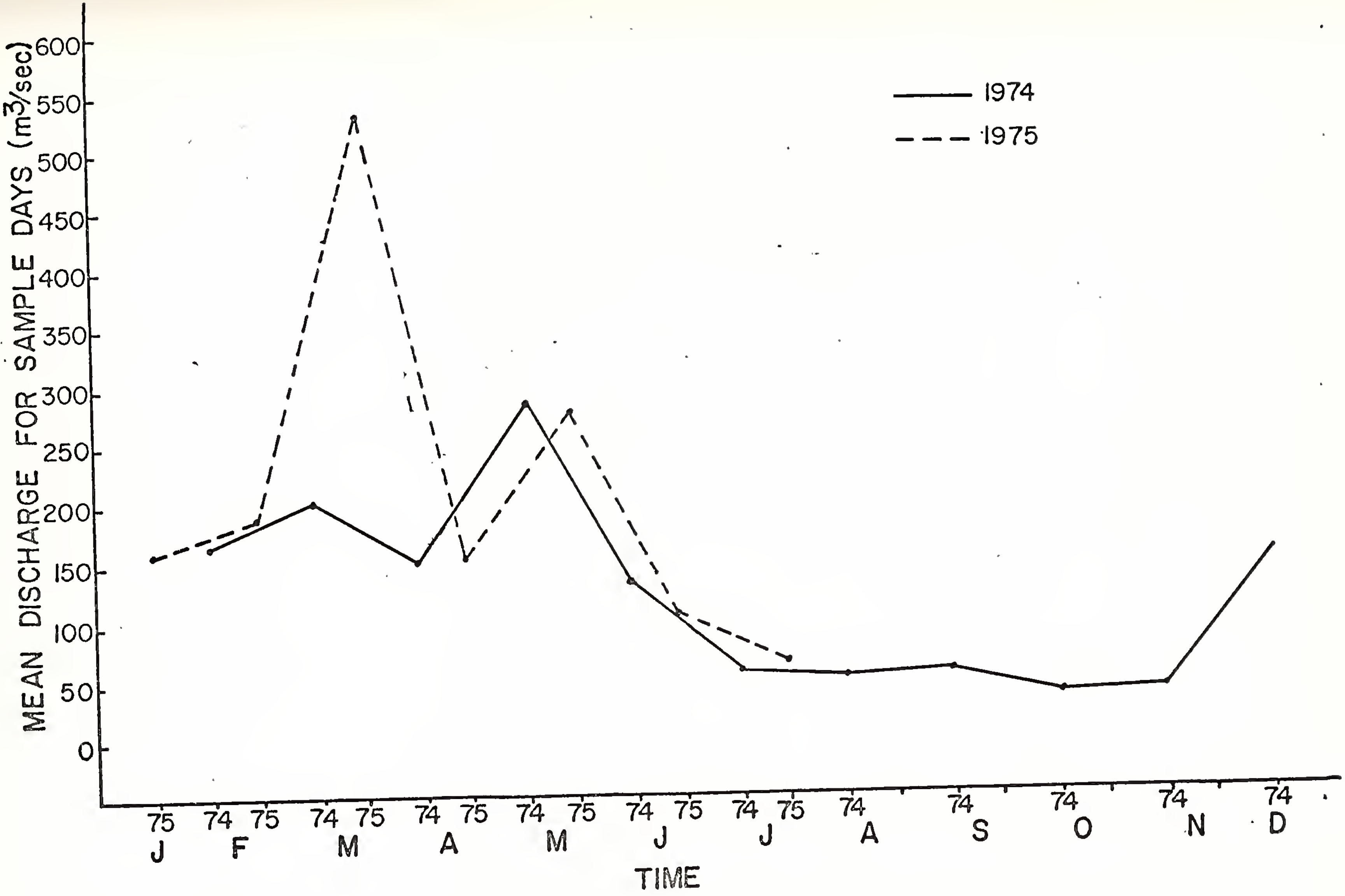

FIGURE 8. Mean discharge of the James River at Bent Creek (station 003) on sample days.

production. High flows also clean out pool areas by removing silt and the settleable materials that coat the bottom. Flows are usually minimal in late summer and early fall. The Bent Creek gauging station supplies discharge data as the stage height in feet which we can then convert to discharge. Flow data is assumed to be comparable at all stations except 006 which is influenced by the Tye River tributary (Figure 1). There are daily variations in stream flow in the study area beacuse of the peaking power dam at Reusens. The mean variation for a low-flow period (October 1974) was 0.24 m. A gauge height of 3-4 feet converts to approximately 50 m^3/sec (1755 ft^3/sec) average daily fluctuation in flow. At high discharge periods the variation is not as appreciable. Kroger (1973) has shown that sudden duress from water flow exposed the streambed and destroyed algae, invertebrates and some fish and probably limited the production of other fish occupying higher trophic levels. These variations in discharge do affect the reaeration capacity of the river. What effect it has on productivity, if any, remains to be determined.

River discharge varied during the 18 month predischarge survey from a monthly mean of 34 m^3/sec in November to 387 m^3/sec in March of 1975 (Table 4). The monthly mean for the entire period is 148 m^3/sec (5385 ft ^{3}/sec) which is approximately 4% less than the mean of 153 m^3/sec reported for the previous 20 years. The range of flow was quite large from a daily mean of 2,105 m^3/sec (74,350 ft^3/sec) on 19 March 1975 to a daily mean of 24 m^3/sec (853 ft^3/sec) on 25 August 1974 (Table 4).

TABLE 4.

Estimated Monthly Discharge at Bent Creek (m^3/sec)

Month	Mean Monthly Discharge	Range max-min	Mean Discharge on Sample Days
1974			
January	326	569-170	320
February	161	244-120	162
March	203	422-125	203
April	176	473-80	151
May	166	824-69	282
June	119	476-61	127
July	60	152-30	62
August	48	128-24	42
September	66	297-27	49
October	37	215-33	32
November	34	103-32	35
December	111	286-35	144
1975			
January	156	637-46	159
Feburary	224	850-114	185
March	387	2,105-61	524
April	134	370-47	156
May	238	680-111	271
June	98	341-36	101
July	61	123-25	67

SPECIFIC CONDUCTANCE

Specific conductance (SC) is a measure of waters' capacity to convey an electric current, a property directly related to the concentration of ionized substances and temperature; it is reported as resistance (umho/cm^2). The major dissolved salts in bodies of fresh water are calcium, magnesium, potassium, chloride, sodium and sulfate. We were concerned with the concentration of the latter three.

The ions in solution influence the kind of life present. Water devoid of dissolved materials is intolerable in nature because pure water will not support aquatic life. Many of these dissolved materials are specifically essential for growth, reporduction and the general well-being of aquatic organisms. Tolerance of external ionic concentrations is dependent upon the osmotic pressure to which the organism is adapted. The total quantity of dissolved inorganic matter is a rough but acceptable index of productivity and standing crop. Other parameters being equal, a stream with a larger quantity of dissolved inorganic ions is biologically more productive than a stream with less. Aquatic organisms can live in a wide range of concentrations of dissolved substances but productivity increases as their optimum is approached.

In general, rivers accumulate progressively larger quantities of dissolved materials as they pass from headwaters to mouth (Pennak, 1971). But, SC decreases downstream in this section of the James from a mean of 222.7 umho/cm^3 at station 001 to a mean of 185.8 umho/cm^3 at station 006 (Figure 9).

Specific conductance of water samples ranged from 105 to 375 umho/cm^3. Analysis of variance shows station 006 to differ significantly from the others at the P=.01 level (Table 5).

TABLE 5.

Results of Duncan's Multiple Range Test for mean specific conductance values at all stations. Underscored means do not differ significantly at .95 confidence level.

	STATIONS					
	001	002	003	004	005	006
mean SC umhos/cm^3	227.1	222.1	217.4	217.5	219.7	185.85

Specific conductance correlates negatively and significantly with river discharge (r=-.569, n=362). Concentration of dissolved salts was seasonal only because discharge varied seasonally. Other factors such as color, the major salts, chloride, sodium and sulfate, all correlated significantly at the P=.01 level. Because of such a close relationship between salt concentrations and water color it is postulated that each of these parameters can be linked to a point-source of discharge upstream. It appears that specific conductance is dependent upon river discharge and the concentration of wastes which enter the river upstream of the study area. The ionic concentration in this area does not seem to exceed the tolerance limits of most aquatic organisms even under low flow conditions.

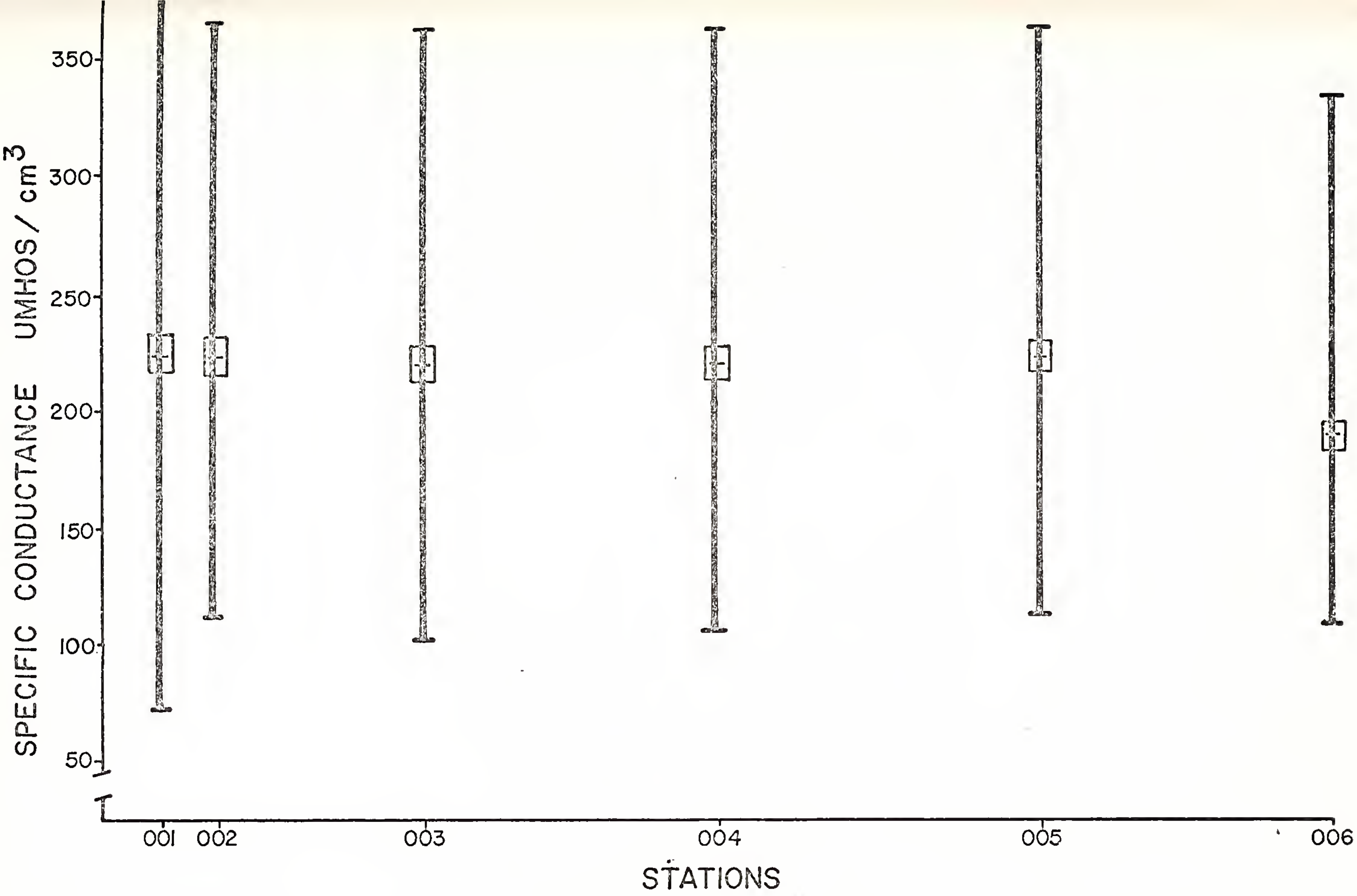

FIGURE 9. Range, mean and standard error cf the mean of specific conductance recorded at each station (pre-discharge).

SULFATES

Natural waters invariably contain sulfate ion although usually not in high concentration. Sulfate leaches from rocks and soils and its presence is usually associated with beds of coal, shale and gypsum in the watershed. Sulfate is also a common decomposition product of organic matter and it may also be found in the atmosphere in various forms where it combines with rain to form sulfuric acid. Sulfates are of concern because they are indirectly responsible for sulfide odor and for corrosion problems. Sulfate is reduced to sulfite by sulfur-reducing bacteria which in the absence of oxygen converts sulfate to hydrogen sulfide, a toxic gas.

All sulfate analyses followed the turbidimetric method (SM 13). All sulfate values were well under the 250 mg/l upper limit set by the U. S. Public Health Service. Sulfate concentrations ranged from a minimum of 8.0 mg/l at station 002 to a maximum of 31.8 mg/l at station 004 (Table 2). One-way analysis of variance showed that the stations did not differ significantly from one another (F=0.46) (Figure 10).

A significant difference in sulfate concentration usually existed between stations on the same sampling date indicating that some of the sulfate in the river was concentrated in "slugs" which may have originated from industrial releases upstream. Sulfate concentration was negatively correlated with discharge at the P=.01 level (R=.572,N=128).

A positive correlation existed between sulfate and color. With 149 paired values the correlation oceffícient was .491, significant at the P=.01 level. The occurrence of increasing levels of sulfate in the James

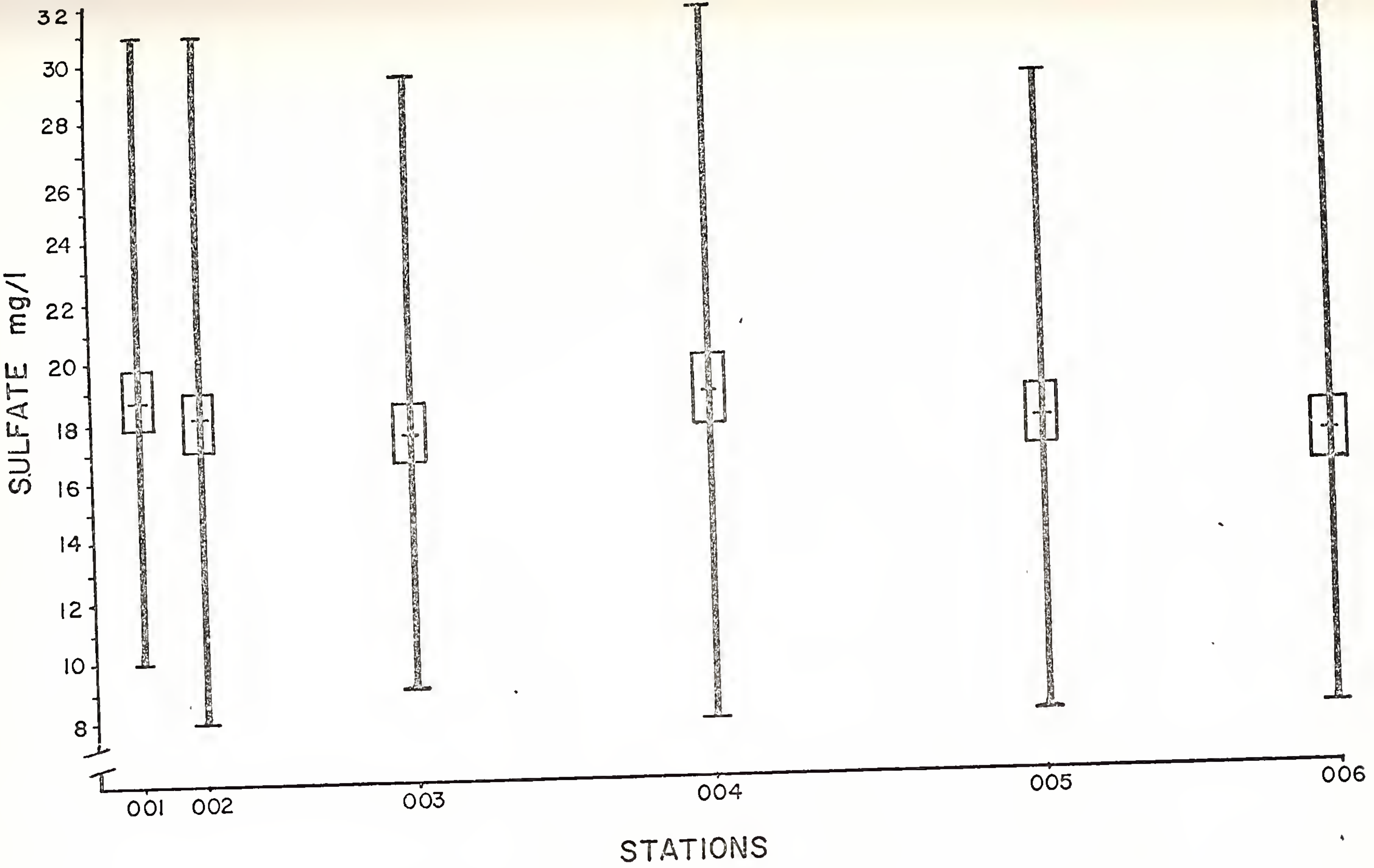

FIGURE 10. Range, mean and standard error of the mean of sulfate concentration of each station within the study area (pre-discharge).

is thus associated with increasing water color. Since most color in the James can be attributed to industrial discharges or organic decomposition it would appear that sulfates also originate from the same sources.

CHLORIDE

Chloride is one of the major inorganic ions in water and sewage. The chloride content of natural waters usually increases as the total mineral content increases. Chlorides come into natural waters in many ways; their salts are readily soluble and leach from rocks and soils. Chlorides in the James are assumed to be from five sources: municipal sewage, livestock, septic tank leakage, breakdown of chlorinated hydrocarbons and runnoff from winter-salted streets. All chloride determinations were made by the potentiometric method (SM,13).

Natural waters 2-300 miles from the ocean usually contain from 2 to 3 mg/l chloride (Ramsey, et.al. 1973). Chloride concentration throughout the pre-discharge survey of the James ranged from 1.26 mg/l in May of 1975 to 32.72 mg/l in December of 1974 (Table 2). Chloride concentration varied little by season although concentration was negatively correlated to discharge at all stations (r= -.59, r=109).

Analysis of variance fails to support the apparent differences among stations (Figure 11) in mean chloride concentration (P = .05). An increase in chloride concentration was positively correlated with increases in alkalinity, color and specific conductance (P=.01). It is probable that chloride, color, sodium and sulfite concentration can be attributed to industrial point sources above the study area. [The only other measured parameter which could be associated with chloride concentration was DO which showed a negative relationship] As expected, sodium concentration is positively associated with chloride concentration significant at P=.01.

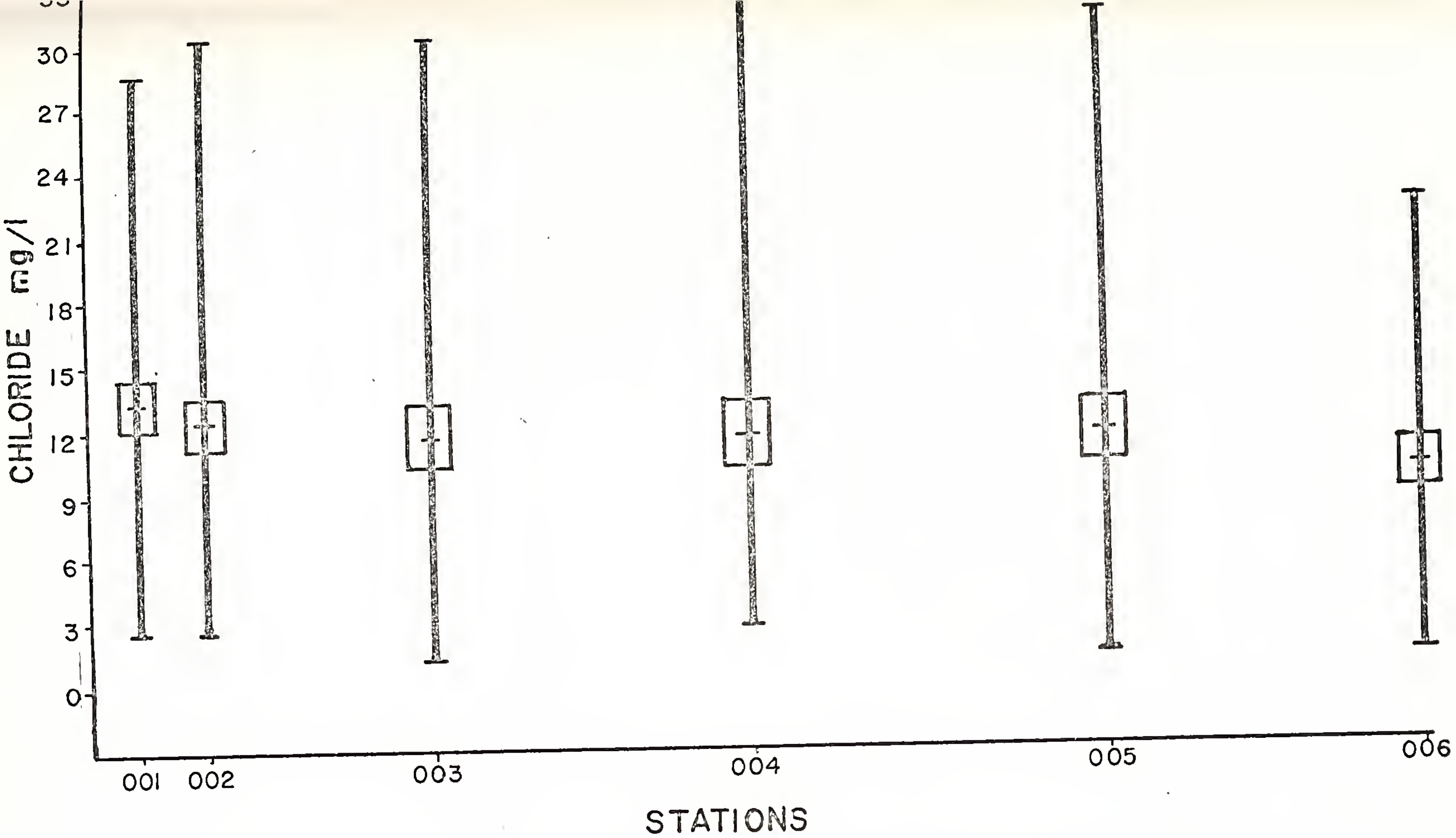

FIGURE 11. Range, mean and standard error of the mean of chloride concentration at all stations within the study area (pre-discharge).

SODIUM

Sodium ranks sixth among the elements in order of abundance, and is present in most natural waters. Sources of sodium are similar to those of chloride.

Sodium concentrations were determined by flame-photometry (SM,13), and ranged from 1.40 to 23.0 mg/l Na^+ (Table 2). Variation in sodium concentration was seasonal only in that discharge varied seasonally. Sodium was negatively correlated with discharge (r= -.433,n=110), significant at the P= 01 level. There was always a variation in concentration between stations on each sampling day indicating variations in sodium input upstream. Analysis of variance fails to support the apparent differences among stations (Figure 12) in mean chloride concentration.

Although the optimum concentration of sodium, chloride and sulfate for the maximum production of this system has not been determined, it is doubtful if these three elements can be considered limiting factors.

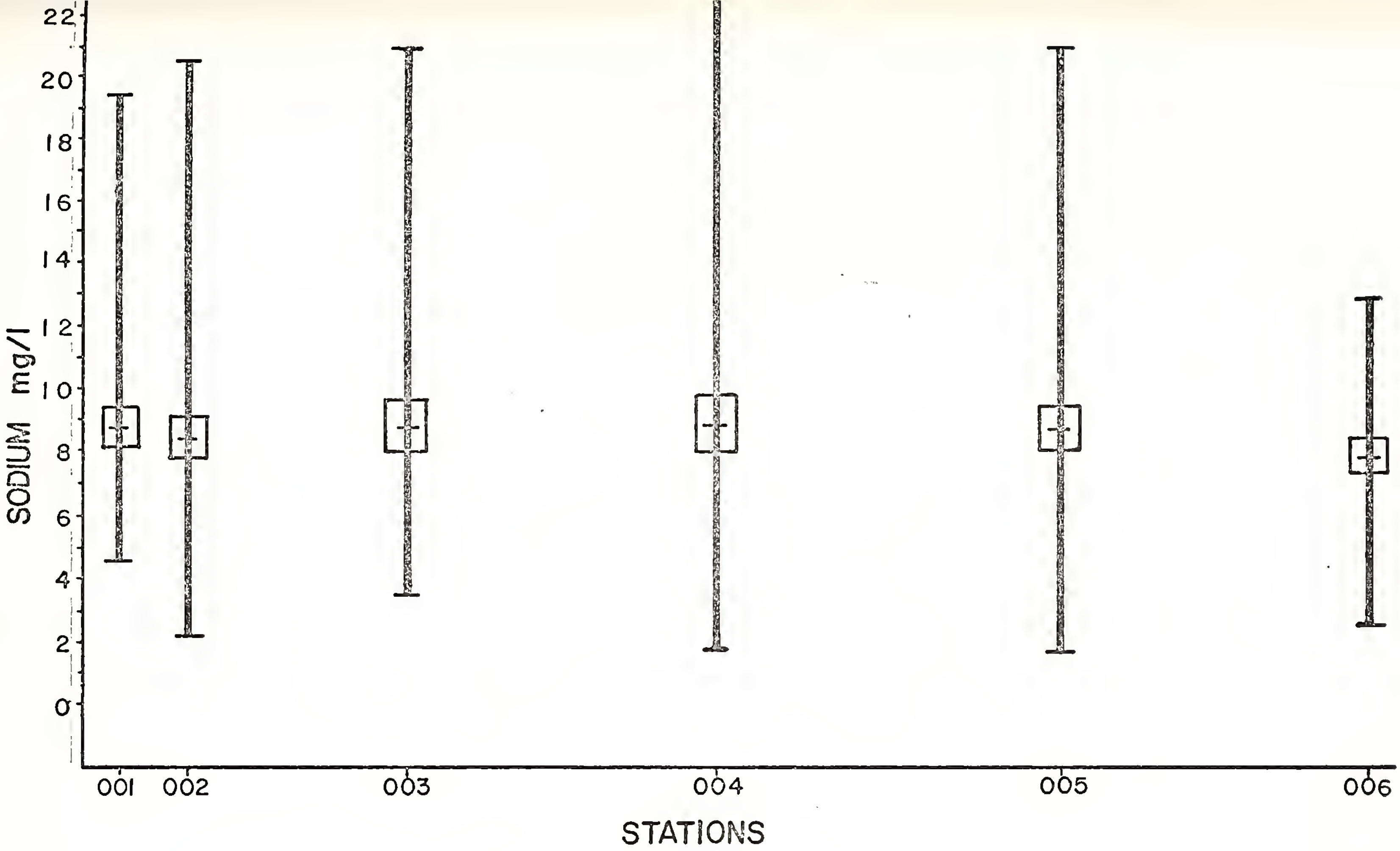

FIGURE 12. Range, mean and standard error of the mean of sodium concentration at all stations within the study area (pre-discharge).

BIOCHEMICAL AND CHEMICAL OXYGEN DEMAND

Particulate organic matter increases bacterial reproduction in a river and leads to more rapid decomposition of foreign substances, such as phelols and free chlorine. Excessive bacterial activity, which results when wastes rich in organic matter enter a river, may bring about a serious decrease in dissolved oxygen. Oxygen-demanding pollutants consume oxygen in two ways, by direct chemical reaction and through bacterial growth. Common constituents of industrial wastes such as ammonia, nitrites and sulfites are readily oxidized in a stream, but the primary process of DO depletion in natural waters is the utilization in aerobic metabolic processes by microorganisms, the usual carbon source or substrate being supplied by municipal and industrial waste discharges.

Oxygen demand is measured by two methods: biochemical oxygen demand (BOD) and chemical oxygen demand (COD). So little reliable COD data was gathered before discharge that it will not be considered here. The 5-day BOD was measured by using the YSI Model 54 instrument equipped with a BOD probe. Most moderately contaminated streams have BOD/5 values of between 1 and 8 (Nemerow, 1974). BOD ranged from 0 at stations 002-003 to 10.15 mg/l at stations 002 and 006 (Table 2). Mean station BOD values ranged from 2.62 mg/l at station 001 to x=2.22 mg/l at station 005 showing an apparent decrease downstream (Figure 13), but the mean BOD concentration of all stations did not differ significantly from one another (F=.876). Little seasonal trend was indicated although BOD values appeared to be generally higher during the spring months of each year (Figure 14). BOD at all stations showed a significant correlation to

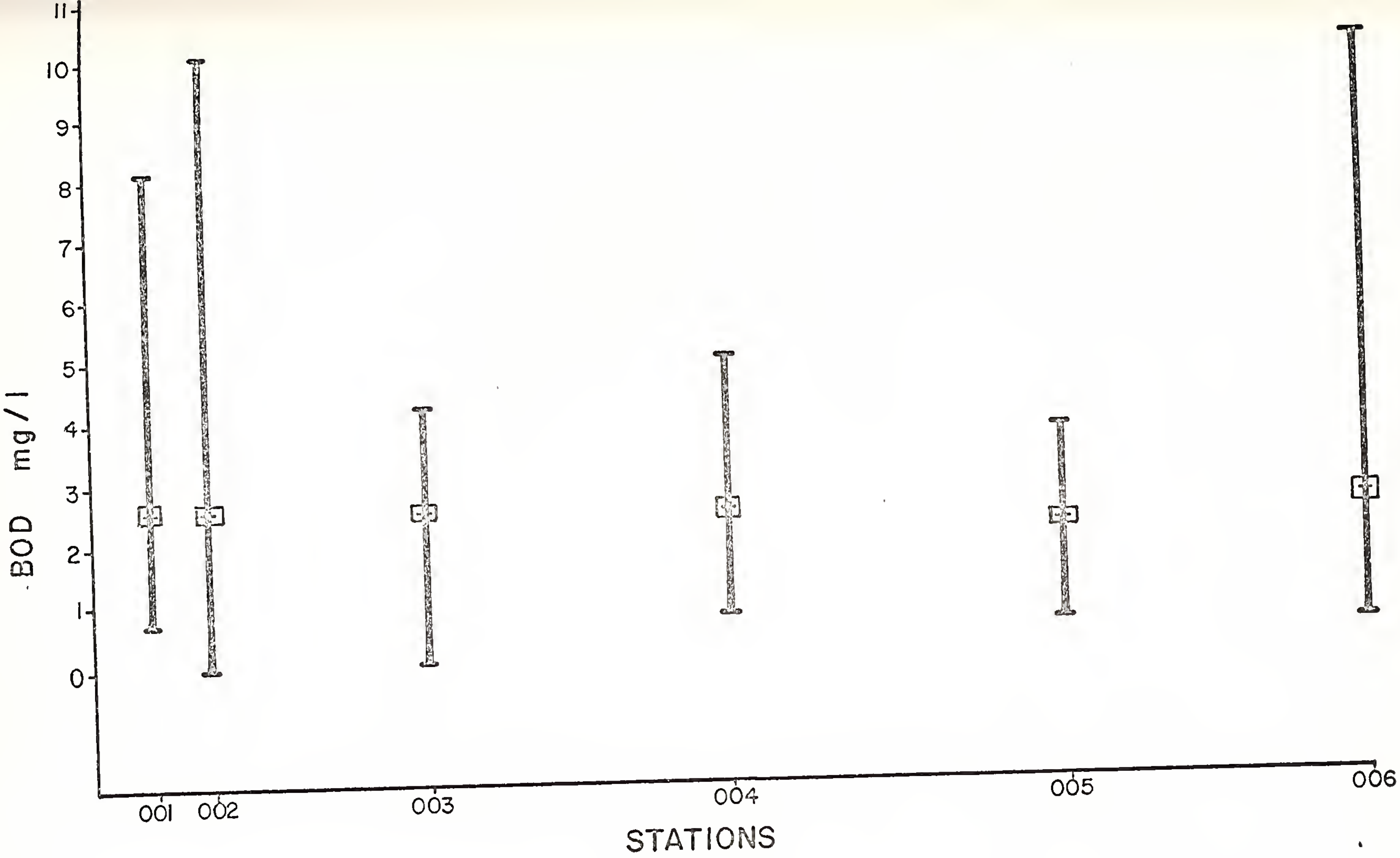

FIGURE 13. Range, mean and standard error of the mean of BOD concentration at all stations within the study area (pre-discharge).

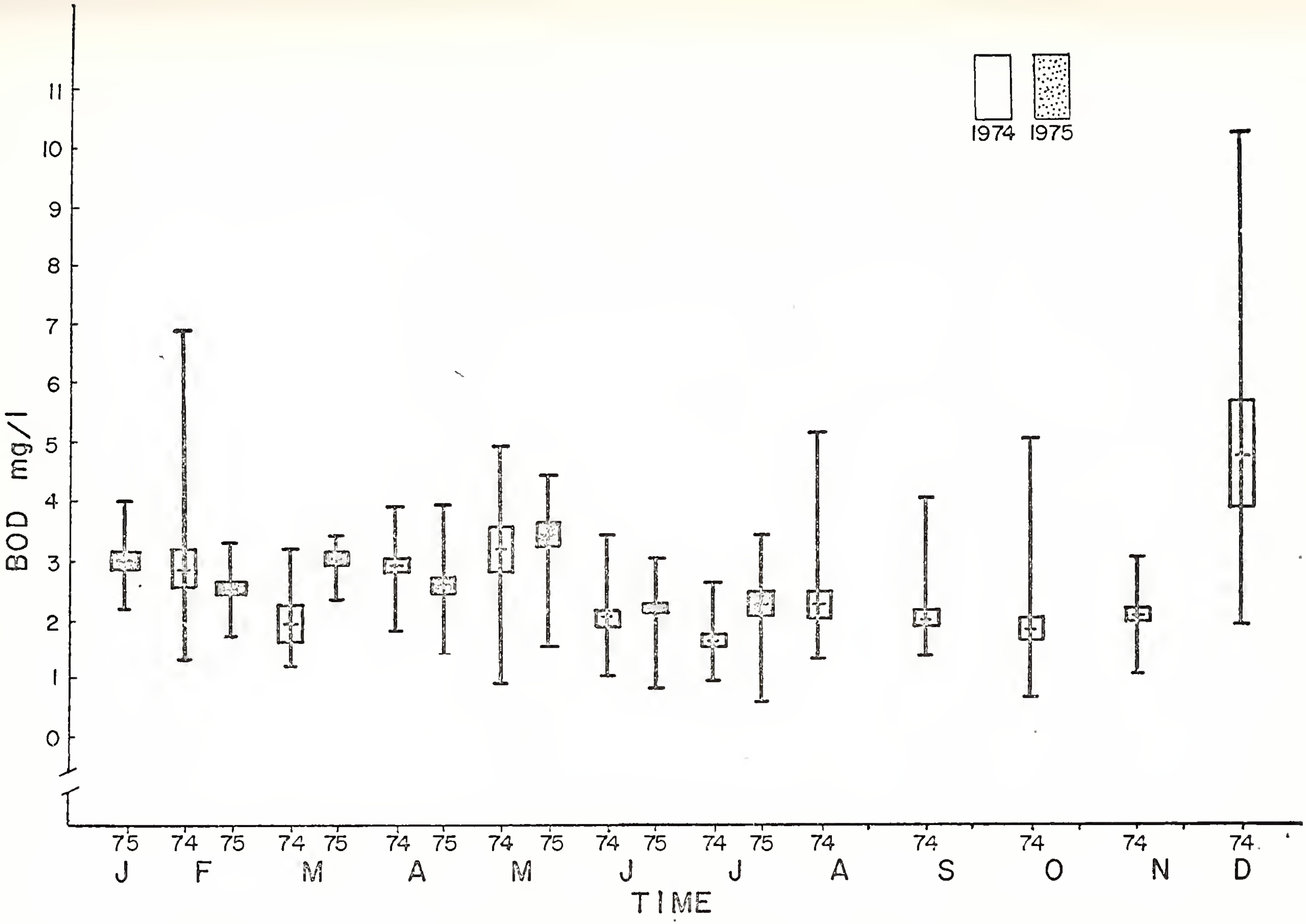

FIGURE 14. Seasonal range, mean and standard error of the mean of BOD within the study area (pre-discharge).

discharge at the P=0.5 level. As discharge increased BOD also increased indicating most loading in this section of river was from organic runoff. A significant (P=.05) correlation existed between BOD and chloride indicating at least some of the BOD in the section of the James is due to the influence of domestic sewage.

Biochemical oxygen demand has been consistently low throughout the pre-discharge study. BOD exceeded the 6.0 mg/1 average limit set by the WCB in only five samples. There was usually some variation in BOD values between stations on the same sampling date. However, one must be cautious in drawing inferences from an empirical test such as BOD. There is limited value in measuring the actual oxygen-demand of grab-samples from flowing waters. The consistently low BOD values indicates that the river has recovered at Riverville from the heavy waste loading it receives upstream at Lynchburg (Table 1).

SOLIDS

Suspended solids may greatly affect the aquatic life of a river. The solids load can be divided into three components: 1) the bed load, 2) the suspended solids load which settle out when current is reduced and 3) the colloidal fractions which remain in suspension unless they are coagulated.

The bed load is carried along the river bed in the region of fairly rapid current. It produces a continually shifting substrate. This condition makes the region uninhabitable for most organisms which live on the bottom or borrow into it. Consideration of the bed load is important in the placement of our artificial substrates.

The suspended solids load and the colloidal fraction greatly hinder the penetration of light into the water. Thus algal growth is greatly reduced so primary production is limited. A river with a heavy supended solids load may take much longer to recover from oxygen depletion due to a heavy organic load. Solids also have a scouring effect on the periphyton and this also limits productivity. The James sometimes requires several weeks to recover fully from the scouring effect of heavy sediment loading. Some macroinvertebrates are also sensitive to the scouring action of suspended solids. Settleable solids were measured in an Imhoff Cone. Non-filterable solids were filtered on to a Whatman glass GF/C filter paper, dried and weighed. Volatile solids are determined as a portion of the total solids by incineration at 550°C (SM,13).

In the James River the suspended solids load is a mixture of clay particles and bits or organic matter. Both types of particles may

provide bacterial substrates. The settleable solids load is usually less than 0.1 ml/l (Table 3) except immediately following periods of heavy rainfall. The greatest settleable solid load was 7.0 ml/l at station 006 on 30 July 1974 (Table 2). The Tye River tributary carries a greater sediment load than the James which results in a greater solids loading at station 006 (Figure 15 and 16). The mean solids concentration did not differ significantly between stations. Suspended solids loading increases downstream in the study area from a $\overline{X}$=12.3 mg/l at station 001 to $\overline{X}$=28.8 mg/l at station 006 (Figure 15). The organic fraction (volatile solids) of the solids load is positively correlated (r=.01) with increases in suspended solid concentration. Volatile solid loading also increased downstream proportional to suspended solids (Figure 16). The volatile component of the total solids load ranged from 16 to 100% of the total. The progressive downstream increase in solids can be attributed to agricultural activity along the river and to stream channelization efforts in the Tye River watershed.

A significant positive correlation existed between river discharge, on the dates of collection, and the levels of non-filterable solids ranged from 2.0 mg/l at station 001 to 208.8 mg/l at station 006 (Table 2). This large range is related to run-off from heavy rains associated with increased river discharge. Turbidity and solids were positively correlated, significant at the P=.05 level. Dissolved oxygen levels decreased as the volatile solids load increased (r=.314, significant at P=.01). The increase in suspended solids was probably partially offset by dilution of dissolved solids which frequently occurs at high sustained river discharge levels (Hynes, 1970).

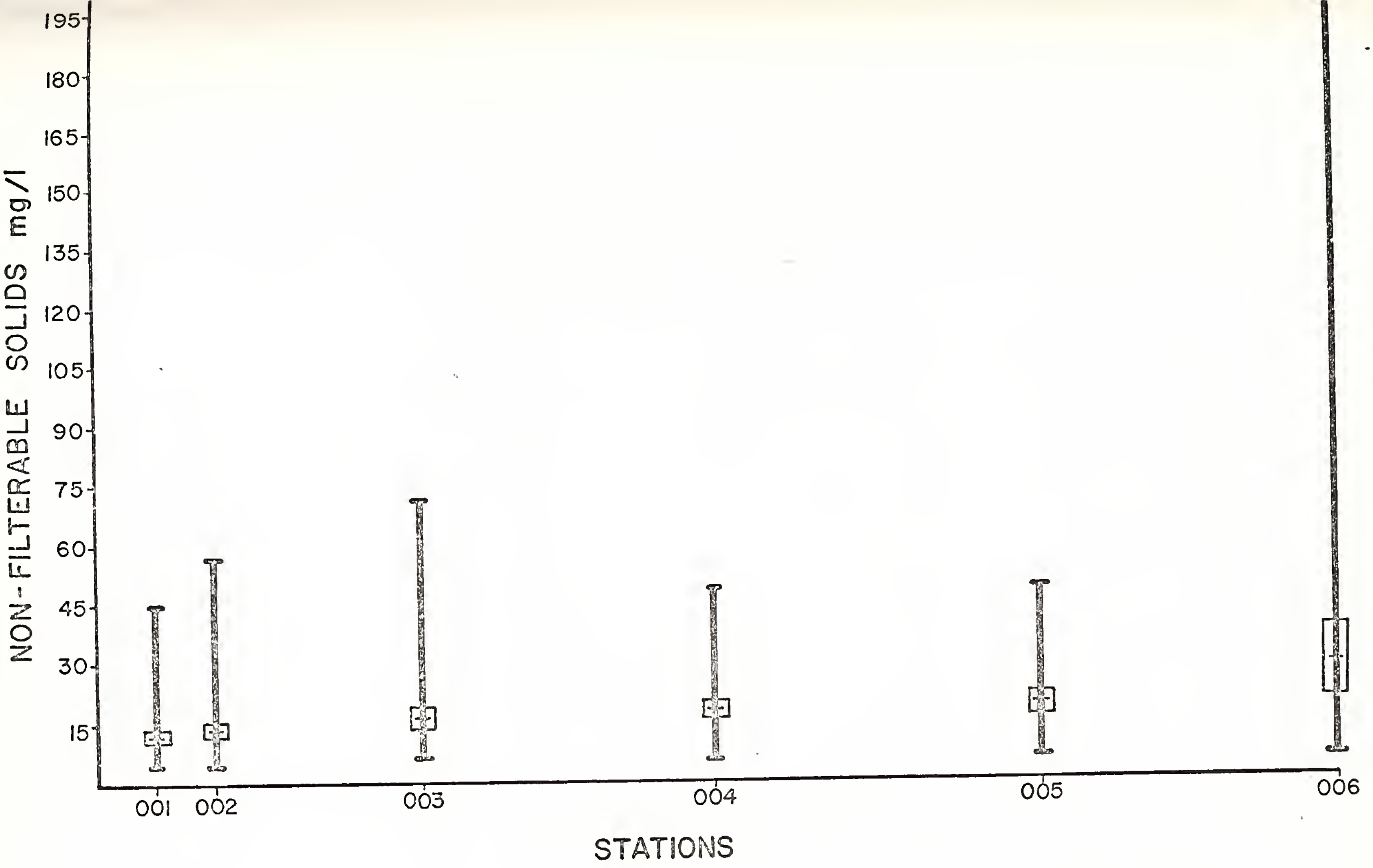

FIGURE 15. Range, mean and standard error of the mean of non-filterable solids at all stations within the study area (pre-discharge).

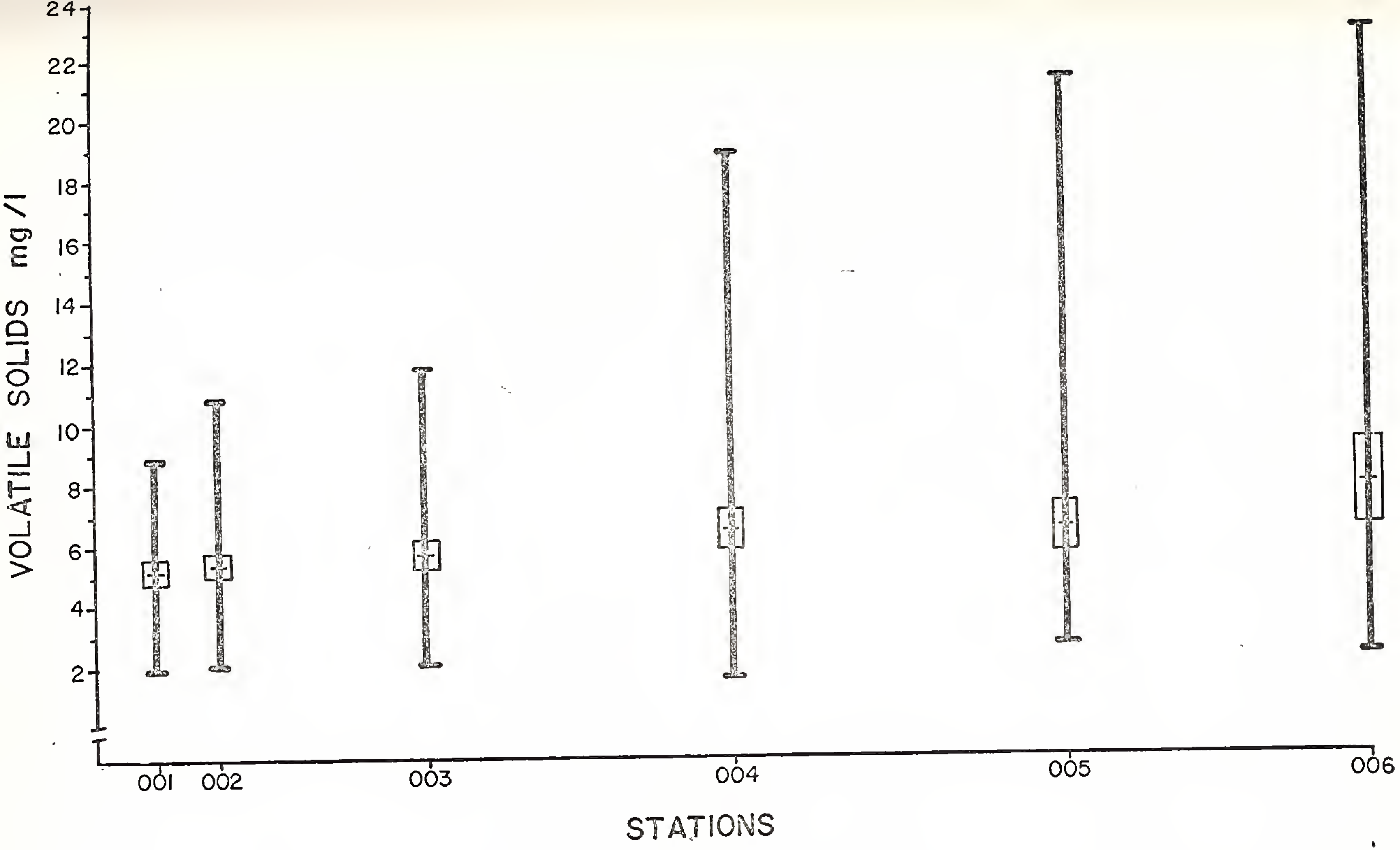

FIGURE 16. Range, mean and standard error of the mean of volatile solids at each station within the study area (pre-discharge).

TURBIDITY

Turbidity in water is caused by the presence of suspended matter, such as clay, silt, finely divided organic matter and inorganic matter and microscopic organisms. Turbidity is an expression of the optical property of a sample which causes light to be scattered and absorbed rather than transmitted straight through a sample. Since the amount of light transmitted through a water column influences productivity, turbidity is an indicator of water quality and productive capacity.

At times of normal discharge the James is relatively clear and becomes turbid following periods of heavy rainfall. The soils in this section of the James watershed contain a high proportion of finely divided red clays which are readily erosive. It is common to find a positive correlation between discharge and turbidity (Dorris and Copeland, 1963) and this segment of the James was no exception ($r=.426$, $N=329$ significant at $P=.01$).

Turbidity was measured by nephelometry in a Hach 2100A turbidmeter (SM 13). The nephelometric method is more precise, sensitive and is applicable over a wider range than is other methods. Results were reported in Formazin Turbidity Units (FTU) comparable to the Jackson Turbidity Unit. The size, shape and refractive index of the particulate materials are of great importance optically, but sometimes they bear little direct relationship to the concentration and specific gravity of the suspended matter. In this riverine system they are related as there exists a positive correlation between turbidity and solids, significant at $P=.01$ level.

A negative correlation was found between turbidity and the dissolved oxygen content of the water. With 391 paired values the correlation was .148 significant at the P=0.1 level. This result can be expected as an increased turbidity would limit the light penetration and thus limit photosynthesis.

While one-way analysis of variance tells us that inter-station *means* did not differ significantly, it is clear that the upper range limits at station 006 were far greater than the upriver stations (Figure 17). This suggests that the Tye River, with its eroding banks and channeled scars, contributes heavy sediment loads to the James following rains.

There appears to be little seasonal trend in the turbidity. The greatest turbidity readings occur immediately following periods of heavy rainfall and may persist for several weeks.

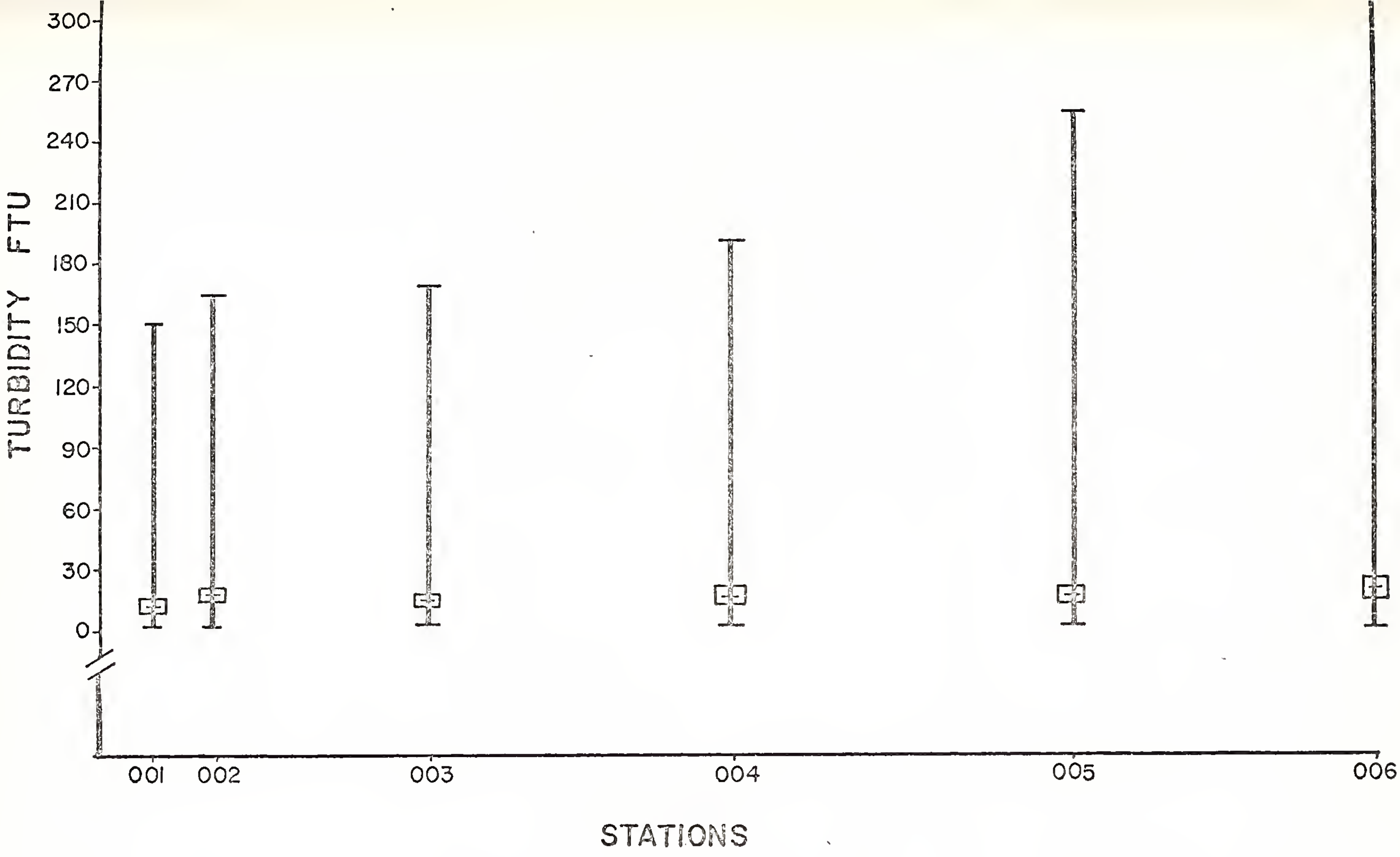

FIGURE 17. Range, mean and standard error of the mean of turbidity concentration at all stations within the study area (pre-discharge).

COLOR

All natural waters have color which derives from decomposition of leaves, wood and the soils through which they flow. Tannins, humic acid and humates, from the decomposition of lignin, are the principal constituents of water color (McCrea, 1933). During periods of flood or heavy rainfall the red clays in the James basin contribute their color. A characteristic tea color is imparted to the river from three paper mills located upstream of the study area. The pulping of wood produces considerable amounts of waste liquor containing lignin derivatives and other materials in dissolved form. Lignin derivatives are highly colored and quite resistant to biological decomposition (Sawyer and McCarty, 1967). Color can then be attributed to substances either organic or mineral in origin, in solution after the suspensoids have been removed.

Color as discussed herein is used to denote "true color," that is, the color of water from which particles have been removed. Water containing coloring matter from natural substances such as derivatives of lignin are not considered to be harmful or toxic. Historically, color pollution has been considered an aesthetic problem, but increased color will reduce light penetration, which in turn affects physiological responses of aquatic life. Color in excess of 50 units may limit photosynthesis and have a deleterious effect upon aquatic life, particularly phytoplankton and the benthos. A significant increase in color may gradually alter gross community productivity and eventually alter higher trophic levels within an aquatic ecosystem.

Color is determined by visual comparison of the sample with a known concentration of potassium chloroplatinate tinted with a small amount of

cobalt chloride (SM, 13). Although this method is not as precise as instrumental methods, it produces sufficiently reliable data for a comparative survey such as this. The unit of color considered as standard is the color produced by 1 mg/l of platinum in water. Results are expressed in color units.

Color ranged from 10 to 120 color units (Table 2). A significant (P=.01) negative correlation existed between color concentration and river discharge (r=-.167, n=355). Color was significantly higher during the fall months (October, November and December) when river discharge was lowest. Color is naturally higher during these months because of leaf fall (Figure 18). There is a direct relationship between the amount of leaf litter in a river and the increase in the concentration of color, specific conductance and bicarbonates (Slack & Feltz, 1968). An appreciable decrease in color was noted during late December and January, 1974-75, when two of the upstream pulp mills were not discharging wastes.

On eight sampling days, water color exceeded the standard of 75 color units established by the Virginia State Water Control Board. Discharge on six of the eight days was one third or less of mean yearly discharge. The remaining two days of high color occurred when discharge was significantly greater than yearly mean. Seven of the high color days occurred during September, October and November whereas the eighth was recorded in July.

Although there is frequently a daily variation in color between stations, mean station concentrations are equivalent (Figure 19).

Hydrogen ion concentration and total alkalinity were both positively correlated with color, significant at the P=.05 level. It appears that

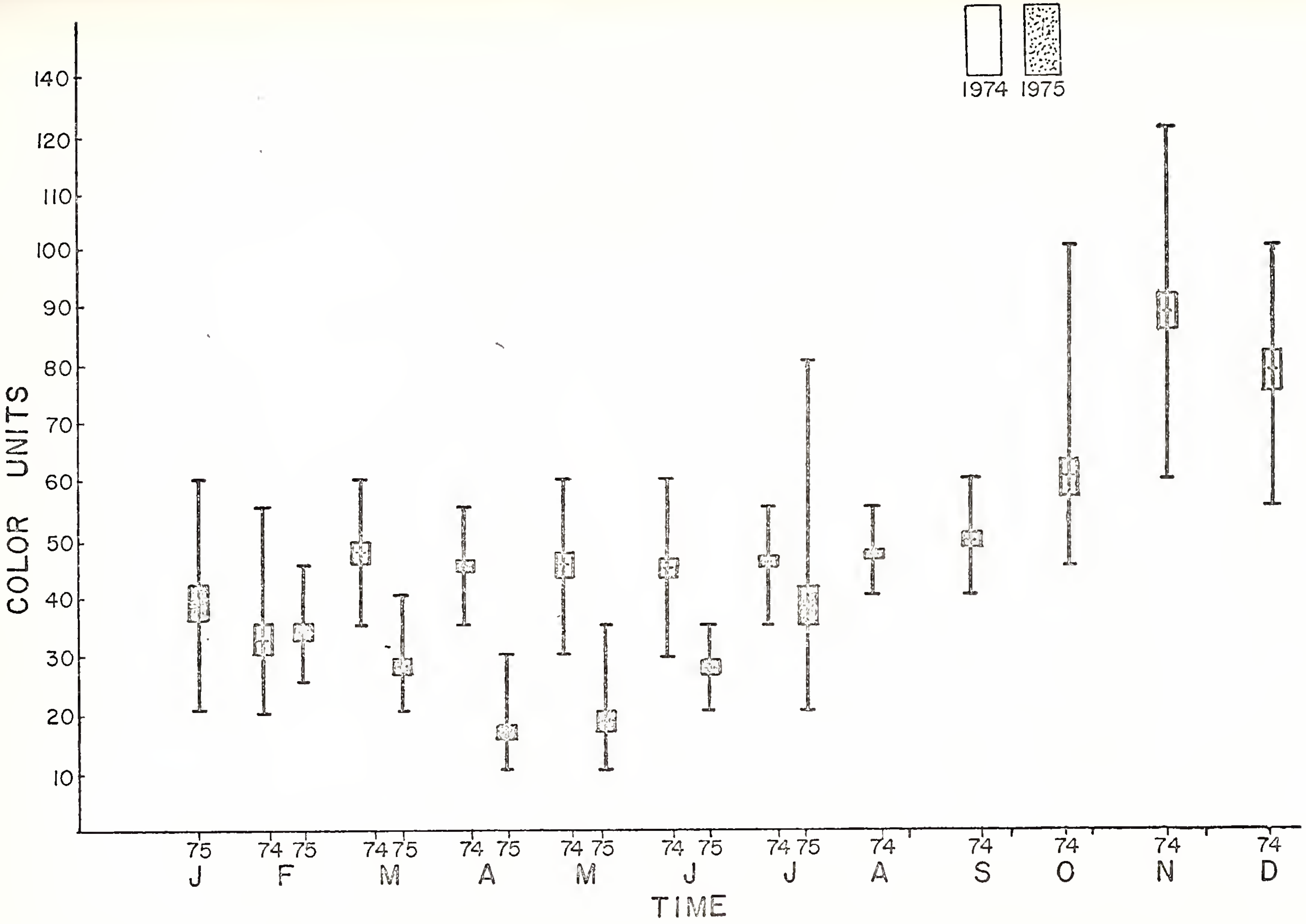

FIGURE 18. Seasonal range, mean and standard error of the mean of color concentration within the study area.

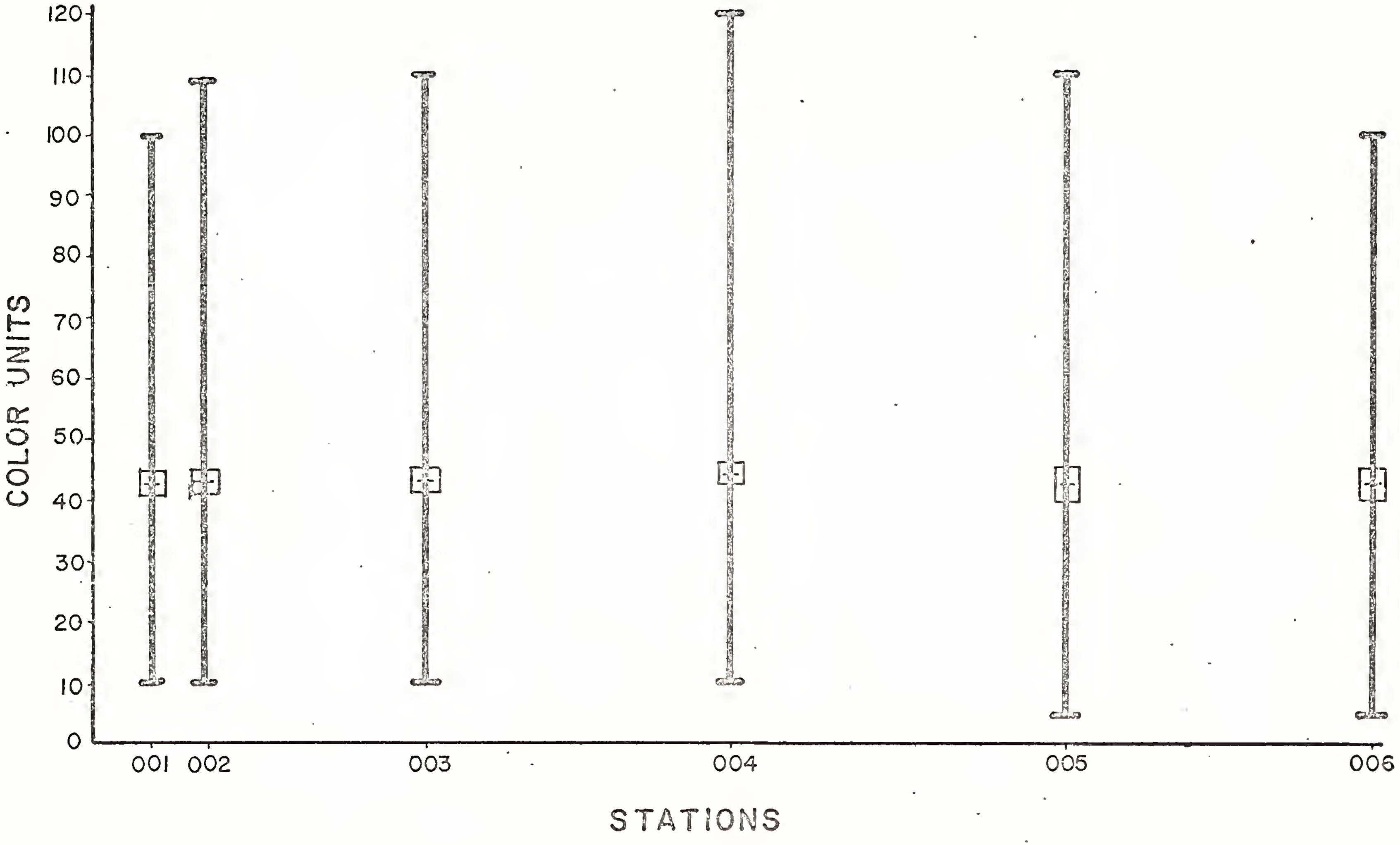

FIGURE 19. Range, mean and standard error of the mean of color concentration at all stations within the study area.

water color is somewhat pH dependent but color showed a closer association with alkalinity probably due to the decomposition of organic carbon compounds. Color could not be associated with solids load, but there was a positive correlation with turbidity significant at P=.01. Color contributes to turbidity in natural waters.

Color may indicate impairment of water quality because color intensity is positively correlated with sulfate concentration and specific conductance (P=.01) and negatively with dissolved oxygen concentration (P=.01). With these relationships in hand, it may be possible to detect point sources of industrial pollution upstream.

pH

The hydrogen ion concentration of most natural waters varies between 6.0 and 8.0. Leached constituents and decomposition products are major factors in the acidity of stream water; in sufficient concentration they can overcome the buffering capcaity of the stream and drive the pH down. The pH of natural waters is also influenced by industrial wastes.

As can be seen in Table 2, pH values within the study area ranged from a low of 6.3 at stations 001, 002 and 006 on February 2, 1974 to a high of 9.35 recorded at station 003 on June 12, 1974. The median* pH value for each station is well within the 6.0-8.5 pH standard set by the State Water Control Board for class IIIA waters (Figure 20).

Doudoroff and Katz (1950) concluded that "under otherwide favorable conditions, pH values above 5.0 and ranging upward to pH 9.0 at least, are not lethal for most fully developed freshwater fishes." Lloyd (1968) stated that "there is no definite pH range within which a fishery is not harmed and outside which it is damaged, but rather there is a gradual deterioration as the pH values are further removed from the normal range. The toxicity of several pollutants is markedly affected by pH changes and increasing acidity or alkalinity may make these poisons more toxic."

Neel, _et_._al_. (1961) found that in general, pH values above 8.0 are assumed to denote the presence of carbonate; a level of 8.0 indicates carbonate alone; and values below 8.0 show the occurrence of free carbon dioxide. "Carbon dioxide, usually produced by decomposition and respiration, will react with any carbonate present to borm bicarbonate and water." Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate when no free carbon

dioxide exists. Carbonates of calcium and magnesium are but weakly soluble and quantities of them leave solution. Decomposition and respiration thus tend to reduce pH and reduce bicarbonate (Neel et.al., 1963). Temporarily high pH levels often are produced in highly productive waters through photosynthetic activity of the aquatic plants by converting the carbonate to hydroxide. Because these high pH values prevail for only a few hours, they do not produce the harmful effects of continuously high levels due to the presence of strong alkalies.

Median* pH was 7.5 at all stations except 006 where the median value was slightly lower at 7.405 (not a significant difference) (Figure 20). The hydrogen ion concentration was consistently higher during the summer in periods of peak primary production (Figure 21). The months of May, June, July, August, September and October are ideal for primary production as the flow is generally low and light penetration is at a maximum.

A positive correlation (r=.383) exists between pH and total alkalinity, significant at P=.01. Plants utilize bicarbonates producing carbonates and raising the pH. Color can also be positively correlated to pH at r=.101, significant at P=.05. It appears that water color is somewhat pH dependent although color is more closely associated with alkalinity (r-.33 with 370 paired values).

Hydrogen ion concentration was negatively correlated to BOD (significant at P=.01) and to DO concentration. Aerobic bacteria actively consume more oxygen during decomposition accompanied by a decrease in the buffering capacity of the river which results in a lowered pH.

The hydrogen ion concentration within this section of river appears to be well buffered with few extreme values. Photosynthesis is assumed

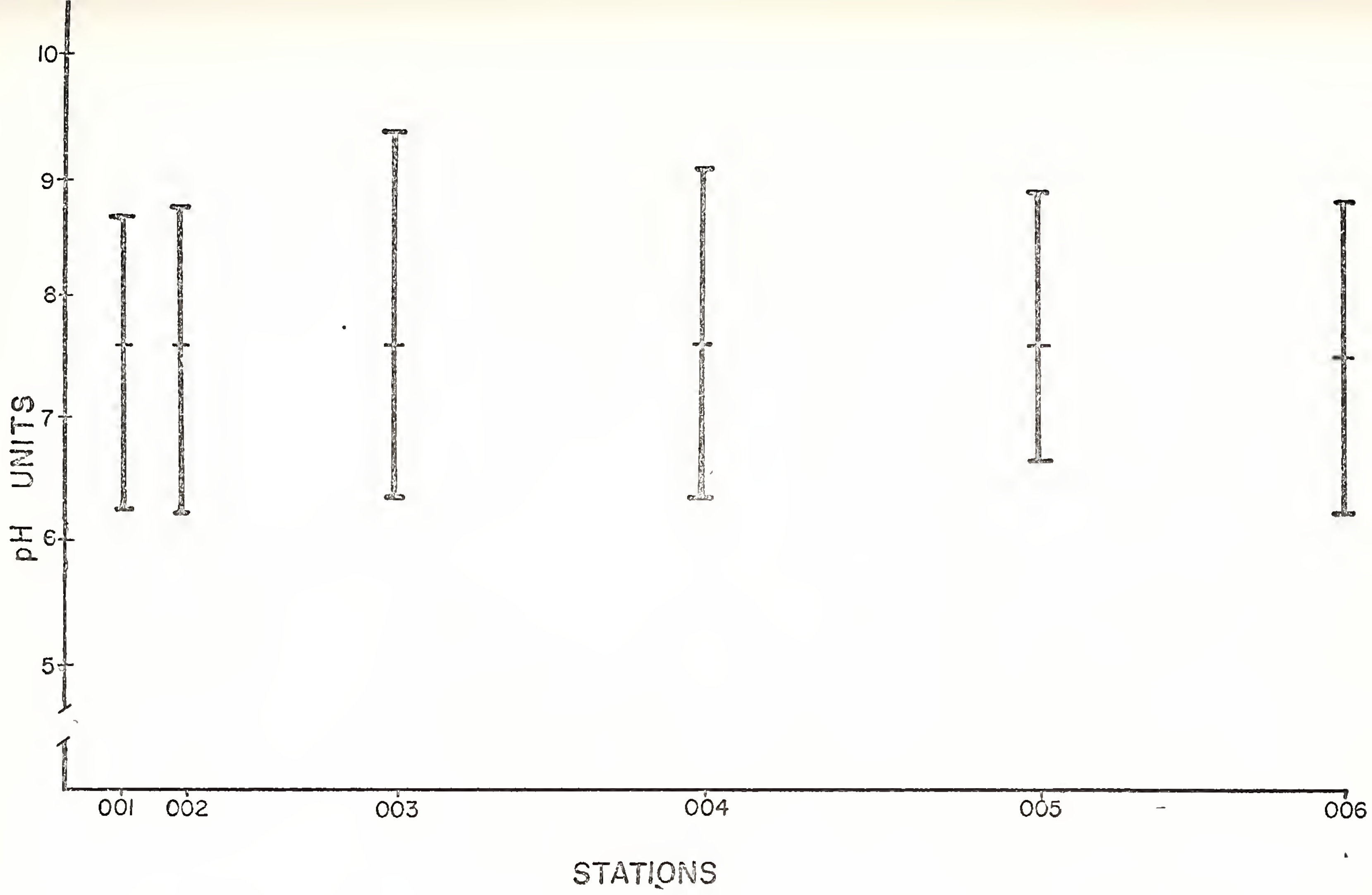

FIGURE 20. Range and median pH at all stations within the study area.

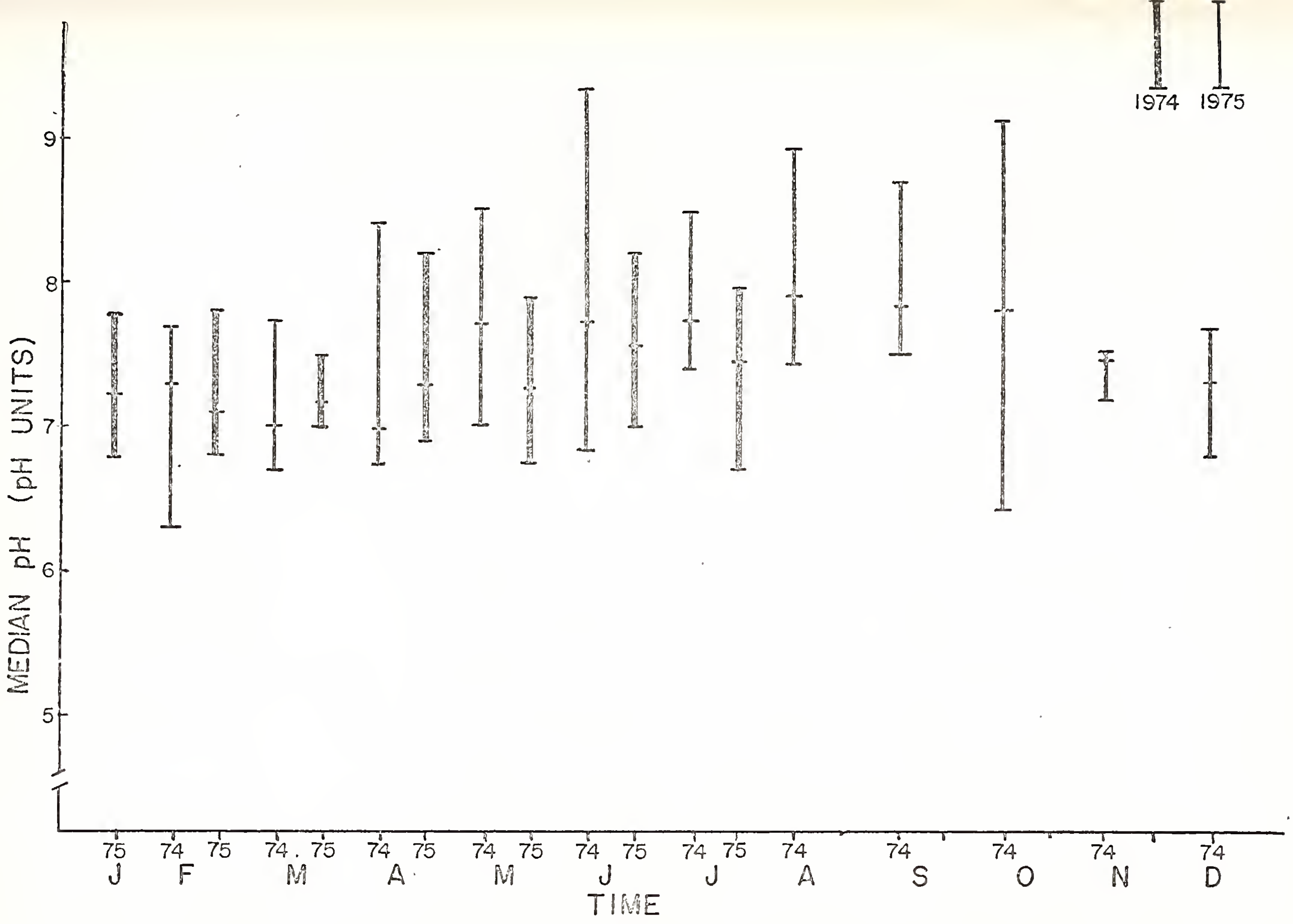

FIGURE 21. Seasonal range and median pH of all samples collected within the study area.

responsible for the high pH values. Hydrogen ion concentration does not appear to be detremental to the fauna of this section of river.

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*From a mathematical standpoint a mean or average pH value has no meaning, as pH values follow the laws of exponents. An average pH value has no meaning in regard to process because the influence of shifts in hydrogen ion concentration is temporal (Barth 1975). Sufficient pH data has been collected so that median (mid-point) values have been calculated.

ALKALINITY

The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural waters is due primarily to the salts of weak acids, although weak or strong bases may also contribute. A significant correlation ($r=.737$, $n=360$) was found between specific conductance and alkalinity. Although not as significant, the same positive correlation also existed for chloride, sodium and sulfate ($P=.01$). The major portion of the alkalinity in natural waters is caused by three major classes of materials which may be ranked in order of their association with high pH as follows: 1) hydroxide, 2) carbonates and 3) bicarbonates. For practical purposes alkalinity derived from other materials in natural waters is insignificant (Sawyer and McCarthy, 1967).

Most running waters are bicarbonate waters in the limnological sense, and they therefore show the complicated relationships among pH, CO_2, H_2CO_3, H^+, CO_3^{-2}, HCO_3^-, Ca^+ and Mg^{++} which are discussed in detail by Ruttner (1963). Calcium bicarbonate in solution is a good buffer system and thus resists changes in pH, but it remains in solution only in the presence of a certain amount of free CO_2. Therefore any process which removes CO_2, as does photosynthesis, tends to cause precipitation of calcium carbonate from solution. The algae removes CO_2, free and combined from the water, to such an extent that pH values above 9 can be obtained (Sawyer and McCarthy, 1967). Generally speaking, alkaline streams support a denser and more diverse bottom fauna than less alkaline streams.

Alkalinity and pH samples were analyzed as soon as possible upon return to the laboratory. Potentiometric titration to end points 4.5 and 4.2 was the method of choice (SM, 13).

Alkalinity values ranged from 24.58 mg/l $CaCO_3$ at stations 001 and 005 to 104.5 mg/l $CaCO_3$ at station 002 (Table 2). Both pH and relative alkalinity values indicated that the river was more alkaline in summer and fall and less alkaline in winter and spring (Figure 22). Station 001 showed the greatest mean alkalinity concentration which gradually decreased downstream through station 006 (Figure 23). Duncans Multiple Range Test shows the mean alkalinity concentration at station 006 to differ significantly from the others (Table 6). An increase in discharge could be significantly correlated with a decrease in alkalinity (r=.51 with 307 paired values).

TABLE 6.

Results of Duncans Multiple Range Test comparing mean alkalinity concentrations at all stations. Value underlined by a common line does not differ at the P=.05 confidence level.

	STATIONS					
	001	002	003	004	005	006
Mean annual alkalinity concentration mg/l	72.25	72.58	70.96	70.97	70.71	61.50

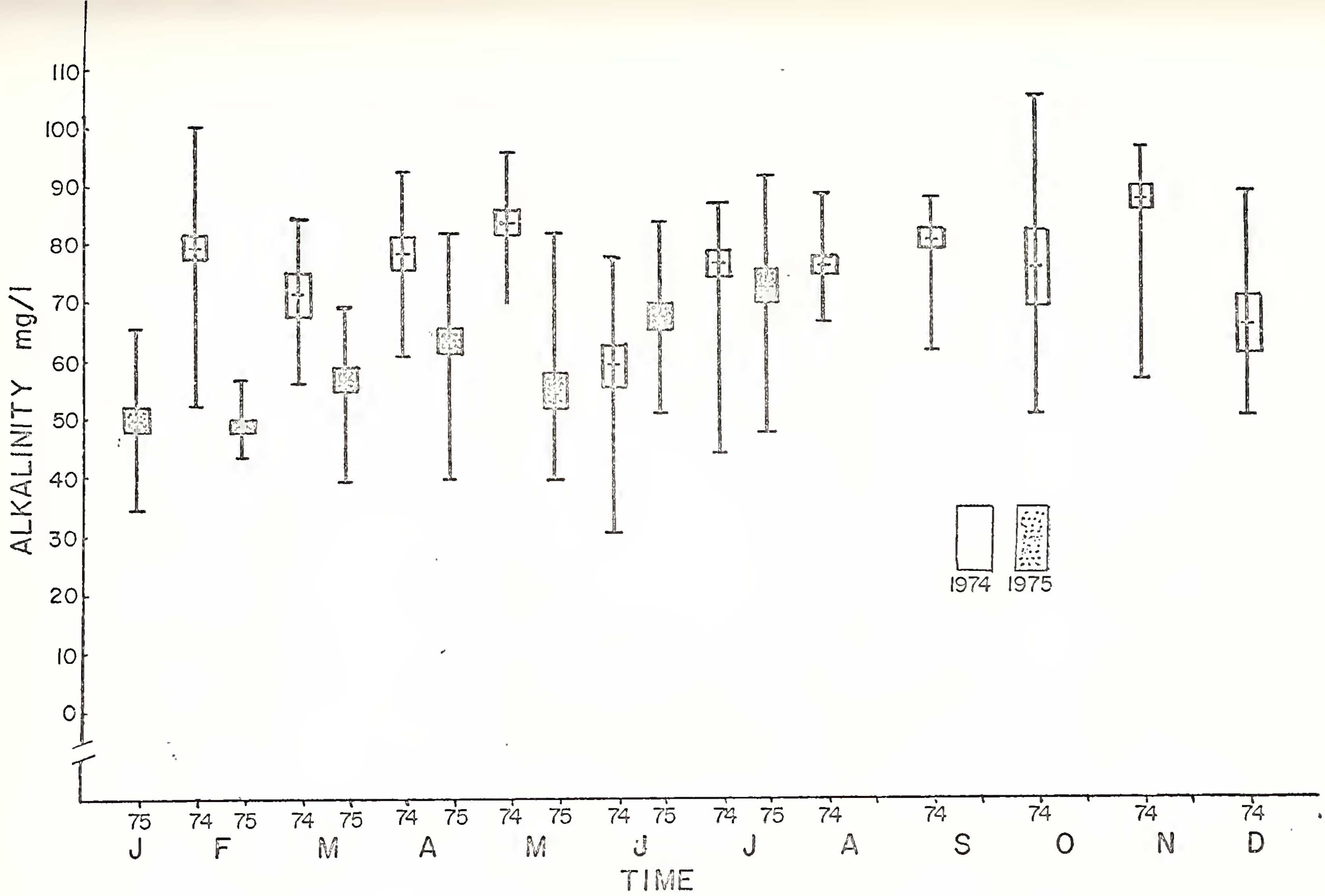

FIGURE 22. Seasonal range, mean and standard error of the mean of total alkalinity concentration within the study area (pre-discharge).

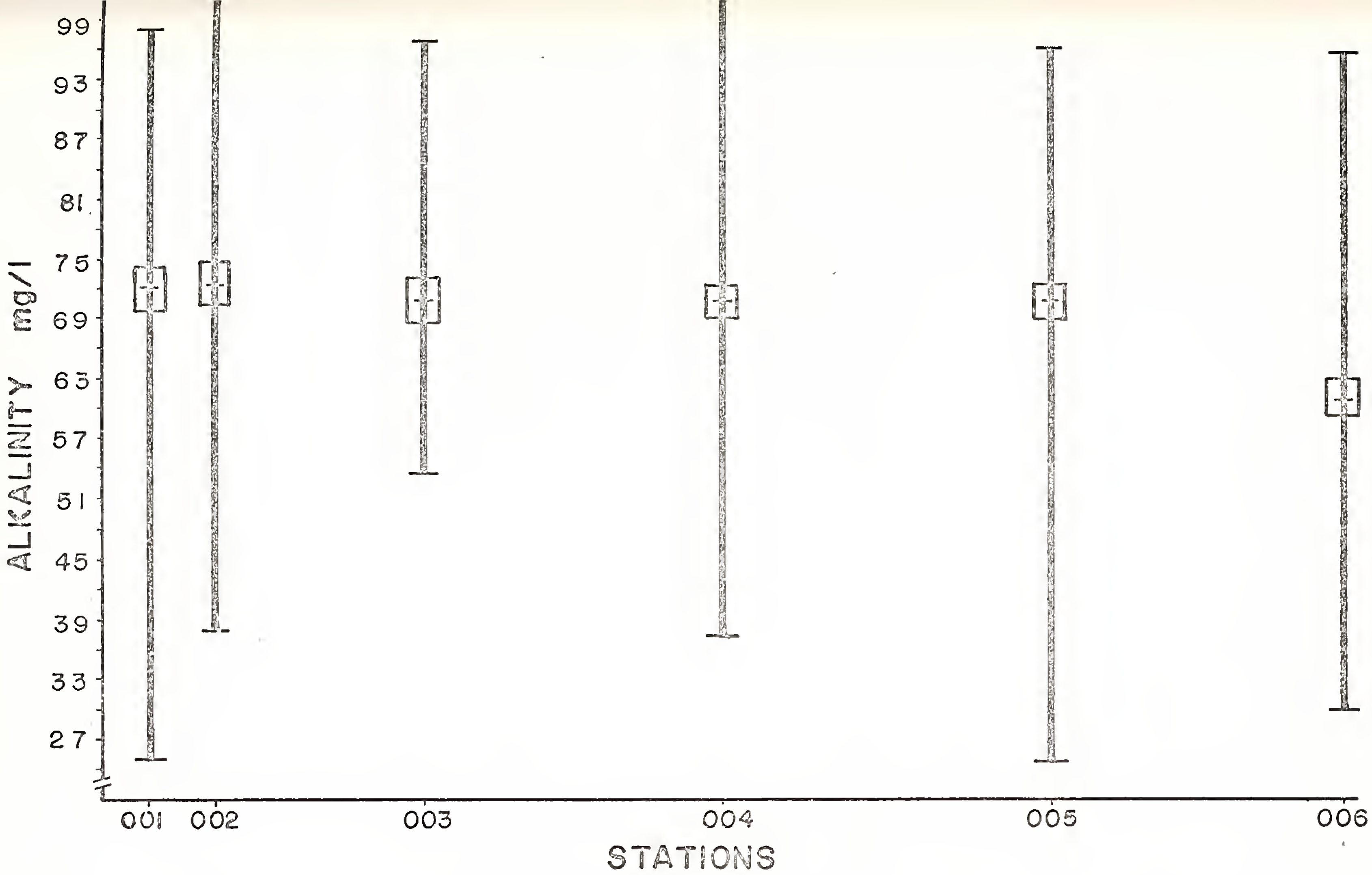

FIGURE 23. Range, mean and standard error of the mean of total alkalinity concentration at all stations within the study area (pre-discharge).

NUTRIENTS

All terrestrial biological processes and most of man's economic activities ultimately result in waste products in various stages of decomposition. A portion of these sooner or later enter surface waters. These waste products include abundant plant nutrients such as nitrogen, phosphorus, carbon and other elements which are subsequently incorporated into organic matter by aquatic plants. The more abundant the nutrient supply, the greater the primary production, if other environmental factors are favorable.

Organic matter and its mineralized products -- ammonia, nitrogen and phosphates -- may have various effects in an aquatic ecosystem. Small amounts may significantly increase the productivity of a river. They are also potentially limiting factors to primary producers in aquatic systems. Measurement of nutrient levels is important in characterizing existing stress in an aquatic system and for establishing the likelihood of interactions.

Productivity of a stream segment responds to slight changes in nutrient level (King and Ball, 1967; Odum, 1956), largely because the flowing water prevents nutrient depletion around the vegetation (Whitford and Schumacher, 1961).

Nitrogen

Most nitrogen in water was originally in the form of organic (protein) nitrogen and ammonia. Organic nitrogen is gradually converted to ammonia nitrogen which is oxidized to nitrite and nitrate. This conversion requires oxygen which can reduce the DO concentration in the river. The major sources of nitrogen entering the James are atmospheric (approximately 5 lbs/acre/year) (Hutchinson, 1957), domestic sewage effluents (Lynchburg), animal and plant processing wastes, animal manure, fertilizer, various industrial effluents and urban and agricultural run-off.

Total Kjeldahl Nitrogen(TKN), which includes both organic and ammonia nitrogen, is the only form of nitrogen we measured. Ammonia is a rather common water pollutant. Clean rivers generally have less than 0.2 mg/l ammonia nitrogen (Nemerow, 1974). The toxicity of ammonia to aquatic organisms depends on pH and the DO concentration of the water. Ammonia is most toxic when the pH is high and the DO is low. McCarthy (1968) indicated that the range of nitrogen concentration in streams usually falls between 0.1-3.0 mg/l with considerable variation in the forms of nitrogen found. Seasonal variations in nitrogen show a higher value during the winter (December through April) and lower values during maximum biological production in the summer (May through November)(Feth, 1966). Johannes (1968) noted that aquatic animals may be the primary source of nitrogenous material in the form of ammonia or amino acids which are readily picked up by algae.

Relatively little TKN data exists because of difficulties with the method (manual digestion-distillation, SM, 13). We found a sharp increase

in TKN concentration following a modification of the original analytical method, so we must question the reliability of some of the higher TKN values. TKN concentration for each sampling day was nonetheless consistent indicating homogeneous water quality throughout the study area. There was no significant difference among mean TKN concentrations at each station. The highest mean TKN concentration occurred at station 006, possibly due to the influence of the Tye River tributary, and the lowest was recorded at station 004. There was little observable seasonal variation in the TKN data. TKN concentration was positively correlated with discharge significant at the P=.01 level (r=.479, n=89).

Phosphorus

Because nitrogen is usually readily available in the aquatic environment, phosphorus is most often the limiting nutrient. The active element phosphorus is not often found free in nature as it usually forms chemical compounds. Mackenthun (1969) gave his considered judgement that to prevent biological nuisances total phosphorus should not exceed 100 mg/l at any given point in a stream.

The range of total phosphate fell between 0.01 and 0.394 mg/l as PO_4. At these levels, when other conditions are favorable, algal blooms may be expected. Total phosphorus is of primary importance. While there is no set relationship between total and available phosphorus (because the ratio varies with season, temperature and plant growth), the total phosphorus is governing as it is the reservoir that supplies the available phosphorus for plant growth and reproduction. It is believed that allowable total phosphorus depends upon a variety of factors; e.g., type of water, character of bottom, turbidity, temperature, and especially desired water use.

Major sources of phosphorus entering fresh water are essentially the same as those for nitrogen. Phosphorus entering an ecosystem may produce a high oxygen demand. One milligram of PO_4 from an organic source demands about 150 mg oxygen in a single pass through the phosphorus cycle to complete oxidation. Thus the oxidation of organic matter, the growth of which has been induced by adding phosphorus may bring about a great reduction of oxygen in a lake or stream.

Station means ranged from 0.088 mg/l total phosphorus at 004 to 0.11 mg/l PO_4 at station 006 (Figure 24). The mean total phosphorus concentration

at stations 001 through 006 did not differ significantly (P=.05) from one another. It appears that the Tye River tributary does not significantly increase the nutrient load to the James River as measured at station 006. (Figure 24)

The ratio of nitrogen to phosphorus is also of importance. The ratio varies with the water, season, temperature, and geological formation and may range from 1 or 2:1, to 100:1. In natural waters, the ratio is usually very near 10:1 (Nemerow, 1974). Ratios of N:P in this segment of the James were not consistent, although a positive correlation did exist between the two, significant at the P=.01 level.

Phosphorus concentrations within the study segment ranged from 0.01 to 0.394 mg/l (Table 2). There was not a significant correlation with discharge and little seasonal variation. Phosphorus concentration showed a positive correlation with BOD (P=.05) but no association with DO concentration. Phosphorus levels were generally above 0.015 mg/l and thus is capable of supporting algae blooms (Sawyer and McCarthy, 1967).

The moderate levels of dissolved and suspended nutrients found within the study area also reflect the relatively low level of organic loading which occurs in the James River immediately upstream of Riverville (VFC). However, it is unlikely that nutrients are a limiting factor in this section of the James. The concentration of both nitrogen and phosphorus is such that it is possible they could lead to eutrophic conditions downstream. Typically, streams draining agricultural watersheds have, on the average, considerably higher nutrient concentrations than those draining forested watersheds.

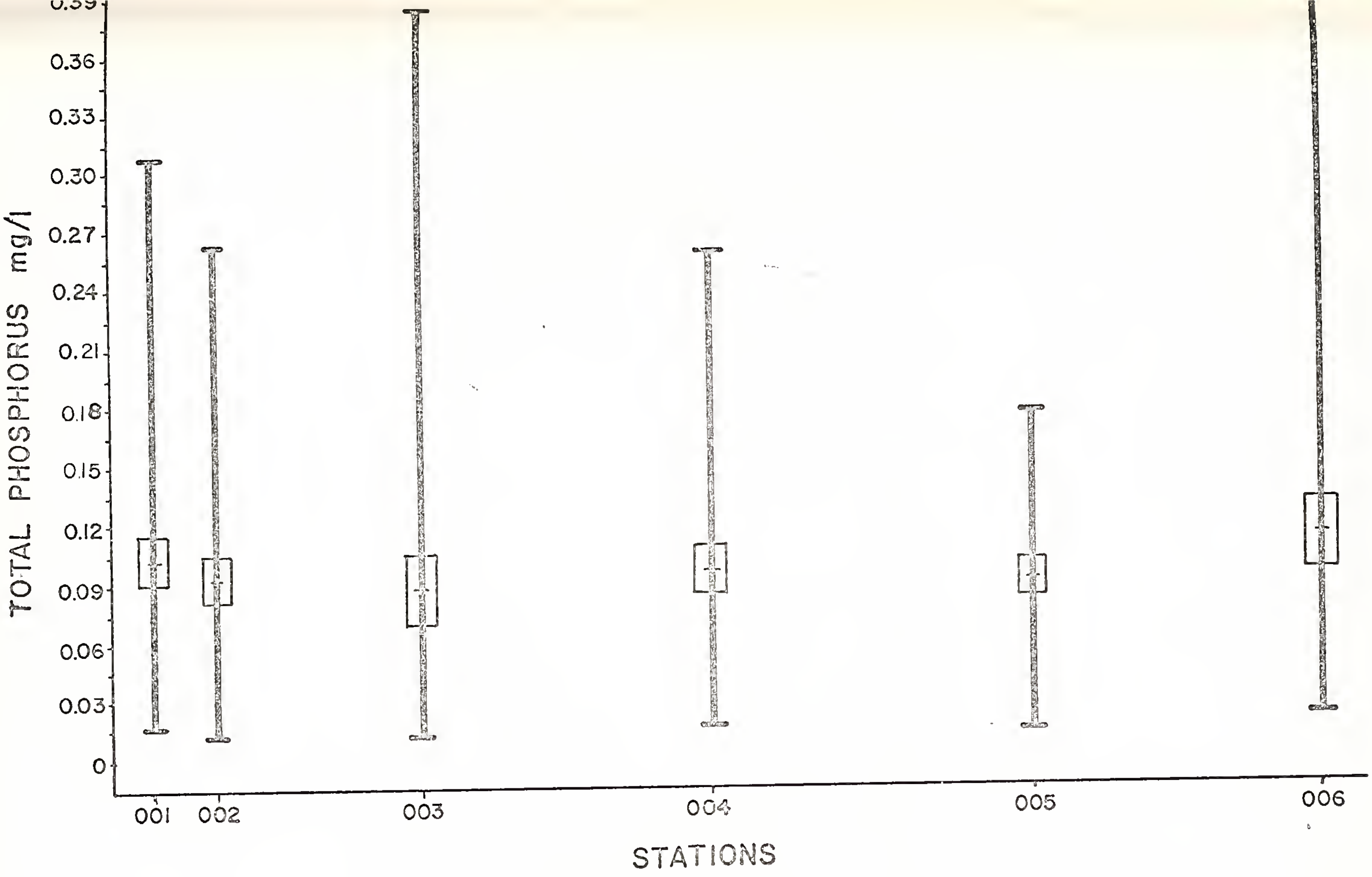

FIGURE 24. Range, mean and standard error of the mean for total phosphorus concentration at each station within the study area (pre-discharge).

SUMMARY AND CONCLUSIONS

We have established 19 months of baseline data on the physical and chemical components of the aquatic ecosystem which may be altered by the VFC discharge; no attempt was made to determine the presence or absence of all possible toxicants. All measured parameters are within the concentration standards set by the WCB with the exception of water color. Color concentration can be linked to both industrial discharge and natural processes in the river.

Interpretation of data based on physical and chemical properties shows the general water quality in the section of the James to be suitable for the support of a dense and diverse fauna (see macroinvertebrate section). The river is probably capable of assimilating a reasonable waste-load providing no toxicants are added and the concentration of organic compounds is moderate. The concentration of all measured parameters was approximately the same at all stations with the exception of station 006, influenced by the Tye River tributary. Only specific conductance and total alkalinity concentration were significantly lower at station 006 due to the dilution effect of the Tye. Although the range of most measured parameters was relatively large, the standard error of the means were consistently small indicating homogeneous water quality.

There is a significant change in water quality in the fall associated with deciduous leaf fall. Linear daily variations exist in water quality within this river segment as a result of industrial and municipal discharges upstream. Many of the variations in water quality are a result of natural biological processes. A lifeless river would have a very different chemical regime.

Streams and rivers cannot be generalized, hence, stream standards cannot be applied wholesale to all rivers without regard to their widely varying natural self-purification capacities. Furthermore, standards cannot be rigidly applied to a particular river as though self-purification capacity remains constant along the course of a stream and from day to day. This study provides baseline data on the ecosystem on which to assess the impact of the VFC discharge.

BIOLOGY

Fecal Coliform Bacteria

Bacteria are usually abundant in streams which receive organic effluents. Since many of them are specialists and associated with the breakdown of organic matter, a succession of species may occur downstream of the outfall. Thus, particular types or associations have been used to indicate varying degrees of purification. The coliform group has been used to diagnose water quality for many years. Since detection of pathogenic bacteria is not easy, *Escherichia coli*, a common nonpathogenic intestinal bacteria that can be detected by fairly simple tests, has been used an an indicator of sewage pollution. This bacterium dies more slowly outside the body than do pathogens and thus provides a convenient measure of the sanitary condition of the water.

Garney and Lord (1952) stated that testing for *E. coli* is universally accepted as the best criterion available for determining the sanitary quality of water for the following reasons: 1) there is no practicable test for specific pathogens, 2) all enteric pathogenic bacteria find their way into water through sewage, 3) fresh sewage always contains an abundance of *E. coli*, 4) *E. coli* is relatively easy to detect, and 5) *E. coli* has a wider range of tolerance than most infectious pathogenic bacteria and therefore a longer survival rate. If *E. coli* is present there is always the possibility of the presence of pathogenic bacteria.

Weekly grab samples were taken in sterilized, 200 ml, wide-mouth bottles. The bottles were always filled below the surface to avoid entrainment of surface film. The sample bottles were immediately iced and returned to the lab for analysis within eight hours. The membrane filter method (MF) (Std. Methods, 13th ed., 1971) was used in the determination

of all coliform densities. Two sample volumes for each station were filtered through type HA, 0.45μ Millipore Filters. Samples were incubated in a water bath at 44.5° C (0.2° C) for 24 hours (2 hours). Fecal coliform (FC) colonies were counted through a stereomicroscope under flourescent lighting.

The FC count was positively correlated with river discharge (N=344, r=0.266; significant at the P= .01 level). The concentration of FC organisms reached its peak immediately following periods of heavy rainfall indicating that most of the bacteria were of agricultural origin.

The three most prominent sources of FC in this section of river are animal wastes via agricultural runoff, septic tank drainage and the municipal discharge of the city of Lynchburg. Although the Lynchburg outfall is approximately twenty-five river miles upstream, it is possible that bacteria from this discharge could be swept downstream into the study area when river discharge is high and other environmental conditions are conducive to FC regrowth. At present, the Lynchburg primary treatment facility is inadequate; during heavy runoff the capacity of the system is exceeded and raw sewage enters the river.

Fecal coliform density ranges from zero to quantities too numerous to count (TNTC)/100 ml of river water. The maximum allowable concentration in this section of the James is a log mean of 200/100 ml within a 30-day period, during which not more than 10% of the samples will exceed 400/100ml. These standards are at times exceeded (Fig. 25; table 7) at each station.

Little seasonal variation in FC density was readily discernable from the data (Fig. 26). Dramatic increases in FC density could always be correlated with moderate to heavy rainfall which occurs in all seasons. Figure 26 illustrates the association between FC increases and river

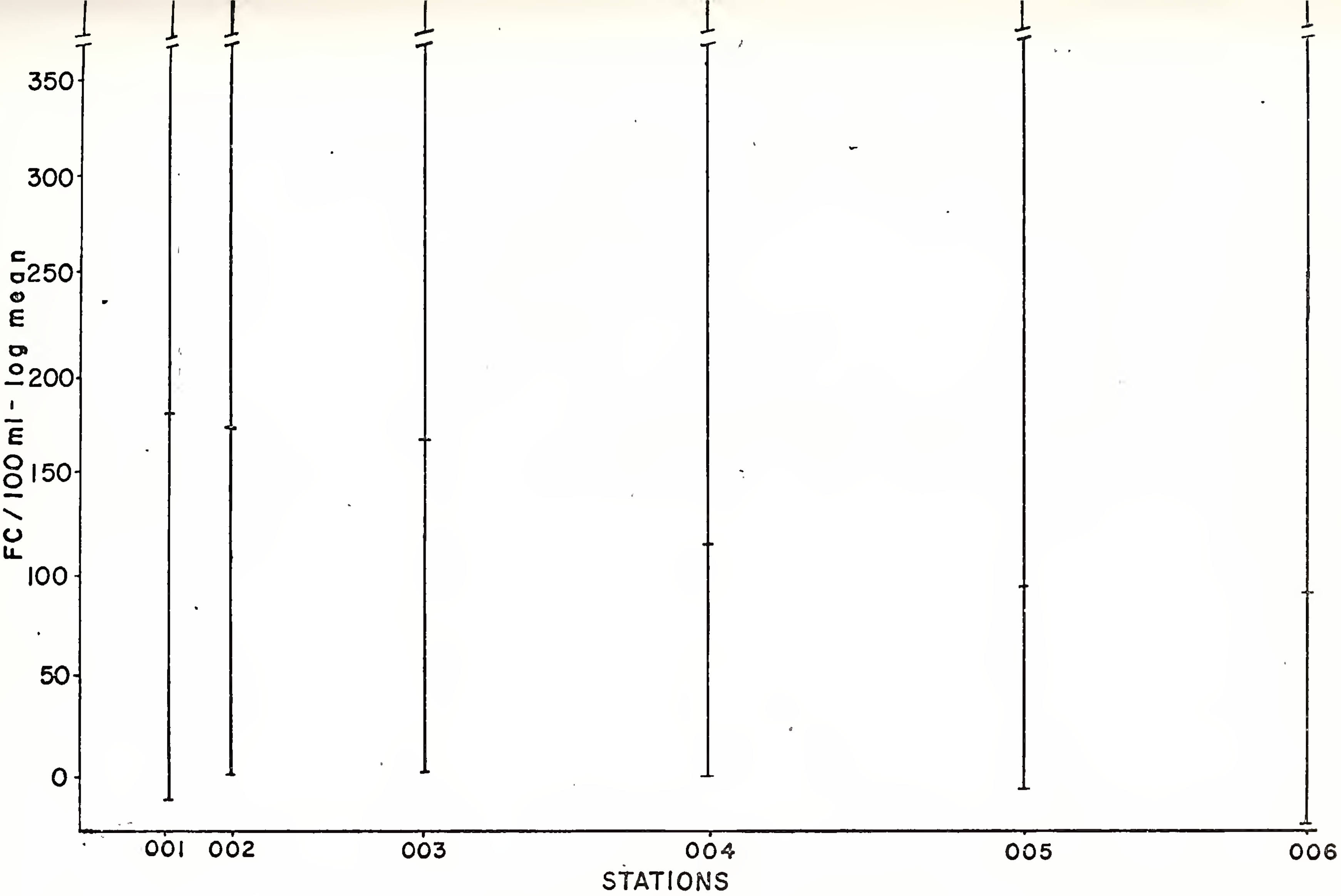

Figure 25. Range and log mean of fecal coliform density at each station within the study area.

Table 7

GEOMETRIC MEAN AND STANDARD DEVIATION OF FECAL COLIFORM DENSITIES BY MONTH, ALL STATIONS

1974	N	Log mean	S.D.	Mean discharge for sample days (m^3/sec)
Feb.	23	51	3.75	1,742
March	21	87	4.27	2,181
April	27	64	4.27	1,625
May	24	163	5.46	3.039
June	22	226	2.92	1.371
July	30	191	3.24	668
August	24	209	2.65	488
Sept.	24	404	4.47	523
Oct.	30	58	4.15	349
Nov.	24	71	3.06	372
Dec.	11	129	3.14	1,547
1975				
Jan.	18	330	6.76	1,711
Feb.	20	79	4.51	1,990
March	15	304	3.39	5,637
April	30	72	3.78	1,682
May	24	267	2.51	2,920
June	24	161	4.01	1,086
July	18	172	2.96	

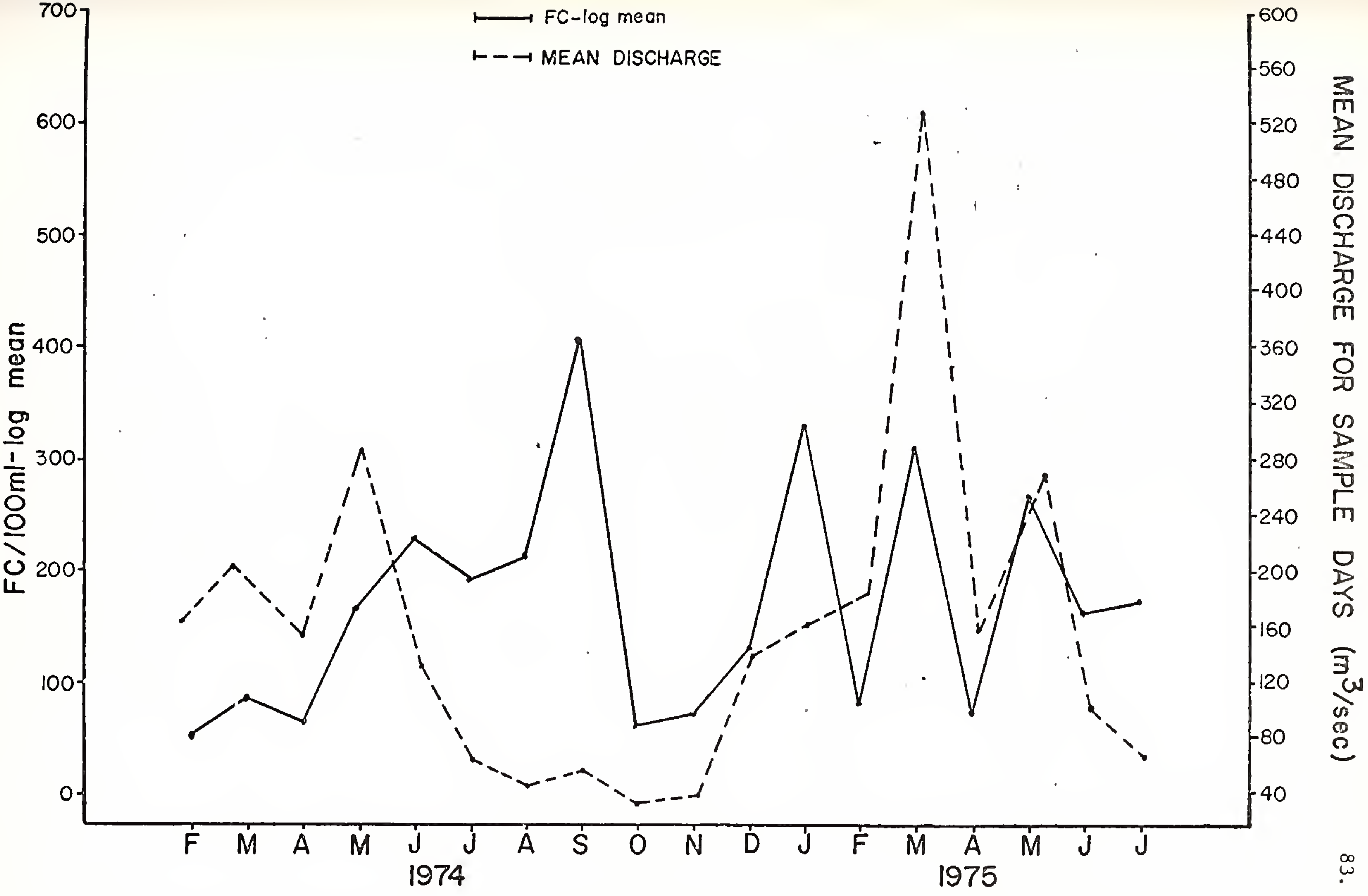

Figure 26. Seasonal variation in fecal coliform density as related to mean river discharge on sample days.

discharge. An increase in discharge is not always accompanied by a corresponding increase in FC density as there is a dilution effect. This implies that although FC organisms are washing off the land during times of runoff, bacterial densities are being further diluted during periods of extremely high streamflow.

Mean FC density decreased linearly downstream from 186/100 ml at Station 001 to 75/100 ml at 006 (Fig. 25). This indicates that the source of indicator organisms is upstream and few additional FC are contributed within the study segment. The log mean FC density at station 001 was significantly greater than the other stations at the 0.5 level (table 8).

Table 8. Duncans Multiple Range test for mean number of fecal coliform bacteria collected during the pre-discharge study. Underscored means do not differ significantly at the .95 confidence level. (Calculated on arithmetic mean).

Stations					
001	002	003	004	005	006
485	398	336	301	318	325

Fecal coliform density could not be significantly correlated with river temperature indicating little if any fecal coliform regrowth under conditions of higher river temperatures. Fecal coliform density was positively correlated with both non-filterable solids and turbidity (significant at the P=.01 level). Suspended particles sometimes serve as substrates for bacteria. These parameters are also positively associated with river discharge.

In summary, it appears that there is a consistent source of FC bacteria above the study segment. Agricultural runoff contributes additional bacteria within the segment which can be correlated with rainfall. The FC density was significantly higher at stations 001 and 002. Except

following a period of heavy rainfall the FC log mean does not exceed the standard established by the State Water Control Board.

PRIMARY PRODUCTION

When algae are present the problem of stream analyses becomes more complicated. River ecosystems are among our most productive when heavily fertilized (Odum,1956). One must take samples throughout the twenty-four cycle to determine the extent of oxygen excursion. Variations in DO due to algal production are most pronounced on sunny days; cloudy, dark weather may result in conditions which can be expected without contribution of oxygen from the primary producers. The photosynthetic effect of algae is most noticeable from around noon to 1500 and least detectable just before sunrise. During the day photosynthesis by algae and other chemo-autotrophic organisms exceeds respiration. At night respiration exceeds photosynthesis. Both occur to some extent during both day and night periods (Nemerow, 1974).

Productivity measurements are important in defining the state of an aquatic community or in investigating a potential impact on a community from an industrial discharge. Productivity of periphyton is influenced by water quality. But primary productivity is the rate of storage of photosynthetically produced organic matter in plant tissues in excess of the respiratory utilization by the plants and other losses during a measurement period. Any disruption of the periphyton community will eventually alter the upper trophic levels in an aquatic ecosystem.

A variety of environmental factors may regulate net primary productivity in aquatic ecosystems. Solar radiation and nutrient availability are certainly the two most important variables, but temperature, available substrate, and grazing by zooplankton and benthic invertebrates may also be important (Likens, 1973).

There are no published data by which the primary production of our river system can be characterized. We estimated net community productivity in the

James by the method of Kelly et al., (1974). Measurements were made at Riverville, approximately one river-mile below the VFC discharge with monitoring equipment provided by the Department of Environmental Sciences, University of Virginia. Signals from an in situ galvanic cell oxygen probe (Precision Scientific) and a thermister were amplified, digitized and recorded every sixty seconds on battery-operated cartridge tape recorders. Solar radiation was similarly recorded from a pyrheliometer located on the river bank. The cartridge tapes were converted to industry-standard computer compatible tapes, which were then reblocked and their data stored as decimal equivalent values of signal voltages.

Recorded data was processed on half-hour averages (appendix B) and used in an exact solution of the oxygen mass balance equation (Hornberger and Kelly, 1972). Net community productivity can in theory be estimated by using a solution of the partial differential equation for oxygen or inorganic carbon mass-balance (Kelly et al., 1974). They found the method to be accurate and to allow estimation of community respiration, gross productivity and relative photosynthetic efficiency. Because productivity varies in a diurnal period, net productivity must be calculated with a Fourier cosine series. Saturation concentration was adjusted to altitude and calculated from the mean of recorded temperature using a polynomial function approximating (to 0.01 mg/1) the data of Truesdale et al.,(1955) For a detailed description of method see Kelly et al., 1974).

Kelly et al. (1974) state that their method for estimating net community productivity should have practical applications for water quality monitoring. Most previous studies of river productivity have depended on a single day's measurements taken at weekly to monthly intervals (E.G. Owens, 1965; Hall, 1972). The variation in photosynthesis and respiration from day to day seems to make

such measurements questionable, except for estimating gross seasonal changes. Community respiration includes the effects of biochemical oxygen demand (BOD) so that the effects of BOD loading changes can be measured. The method is also sensitive to small changes in radiation resulting from decreased light penetration into the water.

"Two major assumptions are implicit in this method. Longitudinal dispersion is assumed to be negligible and reaeration and net productivity are assumed constant with length" (Kelly et al., 1974). Unfortunately, the estimate of daily net productivity is complicated by the high variability in daily flow rates (usually ± 20%) from Appalachian Power Companies peaking power DAM at Reusans, Virginia. The seriousness of this problem is demonstrated by the great sensitivity of the DO Curve to the increased reaeration rates under increased flow. Therefore, net daily production is difficult to estimate accurately with the above method. Until we are better able to compensate for these discharge surges, productivity estimates will not be presented, but several examples of diurnal productivity curves without significant discharge surges are illustrated in appendix C.

Continuous monitors were in place from August 21, 1974 through October 3, 1974. Gaps in the data can be blamed on equipment failure and high water conditions. Twenty-three days of continuous recordings of temperature, D.O. concentration, D.O. saturation and solar radiation and the times of record are presented in appendix B. A summary of this continuous daily data is shown in table 9. Oxygen concentrations during this period ranged from 6.32 to 11.70 mg/l, from 1.36 mg/l undersaturated to 4.23 mg/l supersaturated. Water temperature varied from 19.73 to 28.84 °C, with a slight diurnal periodicity. The D.O. mean for this period was 8.24 mg/l. The mean daytime D.O. concentration was 8.57 and the mean nighttime concentration was 7.82 mg/l. The river was frequently 130% supersaturated and infrequently below 85%

TABLE 9. ANALYSIS OF DIURNAL VARIATION IN OXYGEN, JAMES RIVER, RIVERVILLE, VIRGINIA

DATE	DO RANGE g/m^{-3}	SATURATION RANGE g/m^{-3}	TEMPERATURE RANGE °C	MEAN DO CONC.	MEAN NIGHT-TIME DO CONC.	MEAN DAY-TIME DO CONC.	UNDER-SATURATED g/m^{-3}	SUPER-SATURATED g/m^{-3}
8-21-74	7.51-10-61	7.64-7.93	24.55-26.51	8.88	8.25	9.43	0.32	2.96
8-22-74	7.86-10.97	7.55-7.87	24.96-27.17	9.13	8.54	9.58	0.0	3.39
8-23-74	7.62-11.70	7.43-7.77	25.57-28.17	9.34	8.53	9.99	0.11	4.24
8-24-74	7.25-11.44	7.34-8.68	26.23-28.84	9.28	8.29	10.03	0.27	4.03
8-25-74	6.32-11.23	7.41-7.69	26.20-28.29	8.52	7.26	9.39	1.34	3.82
8-26-74	6.44-10.12	7.38-7.67	26.34-28.55	7.97	7.06	8.65	1.22	2.73
8-27-74	7.11-8.76	7.40-7.63	26.59-28.31	7.85	7.64	8.00	0.42	1.36
8-28-74	6.54-9.47	7.38-7.68	26.22-28.49	7.84	7.77	7.90	1.14	2.08
8-29-74	7.28-9.98	7.36-7.66	26.41-28.69	8.35	7.86	8.75	0.23	2.61
8-30-74	6.67-9.92	7.40-7.64	26.52-28.34	8.02	7.22	8.62	0.93	2.51
8-31-74	6.74-9.48	7.52-7.67	26.33-27.39	7.93	7.24	8.45	0.83	1.96
9-1-74	7.00-8.92	7.56-7.77	25.65-27.12	7.79	7.26	8.19	0.70	1.36
9-2-74	6.74-8.58	7.68-7.84	25.17-26.22	7.60	7.08	7.98	1.07	0.89
9-8-74	8.29-8.41	8.54-8.70	19.73-20.66	8.36	8.36	8.35	0.25	0.26
9-9-74	8.11-8.32	8.46-8.60	20.27-21.15	8.24	8.25	8.23	0.49	0.27
9-10-74	7.94-8.45	8.29-8.50	20.89-22.17	8.18	8.12	8.22	0.42	0.15
9-11-74	7.91-8.36	8.11-8.40	21.52-23.33	8.12	8.03	8.17	0.45	0.24
9-12-74	7.07-7.89	7.88-8.20	22.79-24.84	7.49	7.48	7.50	1.12	0.01
9-13-74	6.62-8.28	7.70-8.07	23.61-26.14	7.35	7.20	7.46	1.36	0.58
9-15-74	7.47-8.67	8.09-8.24	22.51-23.45	8.01	7.97	8.04	0.69	0.58
9-16-74	7.61-9.59	7.96-8.31	22.06-24.36	8.42	8.16	8.65	0.70	1.63
9-17-74	8.14-9.59	8.11-8.25	22.43-23.34	8.82	8.59	8.99	0.04	1.48

saturation.

A typical two days' record (August 25 and 26, 1974) of net productivity is shown in appendix C. Oxygen concentrations during these two days ranged from 6.32 to 11.23 mg/l, from 1.34 undersaturated to 3.82 mg/l supersaturated. Water temperature varied from 26.20-28.55 °C, in a somewhat diurnal periodicity. Saturation concentration varied from 7.37-7.68 mg/l. Conditions were ideal, both days, for high net production; low water turbidity, high solar radiation, and small discharge surges. An examination of the oxygen-radiation graphs for these days (appendix C) shows the increase in oxygen, above saturation, coinciding with the increase in solar radiation. Net production was 4.62 and 1.23 gram oxygen/m^3/day for August 25 and August 26, respectively. In relatively unpolluted waters the D.O. value fluctuates around the saturation value, a state which results from the dynamic equilibrium among the biological, chemical and physical components of the system. Sources and consumers of oxygen are in approximate balance. Gross production to respiration ratios greater than one denote a highly productive community, slightly eutrophic with little organic loading. The James through this section has recovered from the effects of Lynchburg and is capable of assimilating a reasonable amount of organic loading. Hynes (1970) concluded that only in limited situations, or where pollution has materially altered the nutritive status of the water, does local primary production supply more than a proportion, possibly a very small one, of the energy used by a running water ecosystem. It has been shown by Likens (1973) that the productivity of rivers may range down to less than 1 mg carbon/m^3/day. This ecosystem is very productive due to the enrichment it receives from Lynchburg and other sources upstream.

Macroinvertebrates

Chemical analysis of a grab sample may tell us a great deal about the composition of that sample of water at one time in one place, but the information may not be relevant to our concern for the ecological health of the river. The most comprehensive method for evaluating the impact of an industry upon an aquatic ecosystem is to assess the living community itself. The composition of an aquatic community is determined by recurring critical conditions of short duration as well as by long-term factors. Thus a local complex of organisms is indicative of the environmental conditions which have occurred during its development. This kind of biological analysis, though less precise in measurement, is diagnostic of the long-term effect of water quality.

Many investigators have shown that physio-chemical and biological data differ widely when several factors interact to cause ecological change. Ecological change should be defined by biological conditions (Hynes, 1961). In anticipation of the 6 million gallon/day effluent from Virginia Fibre Corporation, we have chosen to characterize the structure of the macroinvertebrate community. Gaufin and Tarzwell (1952), Kemp, *et al.* (1966), Wilbur and Dorris (1967) and Harrel (1969) pointed out the following characteristics of macrobenthos that make them especially suitable for evaluating the conditions of rivers and streams: 1) extreme range of tolerance to varying environmental conditions, 2) sufficiently long life cycles to reflect conditions for an extended period of time, 3) low motility, 4) central positions in aquatic food chains, 5) sampling technique for bottom fauna are more reliable than techniques for fish and 6) it is likely that more biological information per dollar invested can be gained from studying this group than any other group of organisms.

A disadvantage of a biological study is that it can only reveal the general type of pollution; it does not indicate the exact substances involved. it can distinguish between organic and toxic pollution, but it does not usually identify the particular poison which damages the community.

Some regulatory agencies request aquatic ecological information for all trophic levels. Since all trophic levels are interrelated, an impact at one level may influence the entire ecosystem. However, impacts initiated at one level, and the degree to which they are reflected varies. By intensively studying one important community in the ecosystem we are able to assess any stress caused this ecosystem by VFC.

Unfortunately, there are few specific types of organisms which correspond only to each specific type of water condition (associations are general). Each organism requires a certain environment in order to exist; thus every new change in environmental conditions can be detected in changes in the benthic community. Those individuals more tolerant of environmental changes are often the only inhabitants of a polluted stream. Thus in polluted waters there is a decrease in the variety of species present and this lack of species diversity is a sign of an unstable environment (Odum, 1972)

Communities respond to stresses by shifting in structure, i.e., changes in the kinds and numbers of species present and the number of individuals per species present. An unstressed community typically has a great number of species with relatively few individuals of each species. When a community is under stress, the number of species is likely to decrease and the number of individuals of the remaining species is likely to increase. Such changes in community structure are easy to measure when the stresses applied are severe. However, subtle stresses can result in subtle changes in communtiy structure and such changes are masked by normal variations.

Structural studies of levels of organization larger than the species

are based on the assumption that actions of the abiotic environment and co-actions among the biotic components result in a characteristic assemblage of organisms. Cairns (1974) stated that the use of community structure to assess pollution is based on four assumptions: 1) natural systems tend toward diversity, stabilizing at a point where further diversification has no selective advantage, 2) diversification increases the functional complexity of the system, 3) diverse communities are more stable than simple communities because the elimination of one species will affect a greater proportion of the biomass of a simple system than a diverse one and 4) pollution stress will simplify the diverse communtiy by eliminating the more sensitive species (unaffected species become abundant because of reduced competition). Patrick (1967) demonstrated that species composition in a freshwater stream is constantly changing while the diversity remains fairly constant.

Although the relationship of species diversity to ecosystem structure and function is not well understood it seems reasonable to assume that a decrease in diversity results in simplification of the functional structure and energy flow of the community. The more simplified the community structure, as indicated by a drop in diversity the more probable it is that a loss of a single species will have a major effect.

The purpose of this aspect of the study was to establish baseline data on the density and diversity of the macroinvertebrate community in the section of the James which will be influenced by the VFC discharge. These measurements were correlated with physico-chemical data in an attempt to describe community structure.

Materials and Methods

In order to determine macroinvertebrate community structure several standard sampling techniques were employed. The nature of river bottom substrate and the depth of the river in most areas did not lend itself to sampling with conventional square foot and grab sampling devices. By using artificial substrates we standardized the substrate and eliminated discrepancies that would result if organisms had a preference for a particular substrate. Simmons and Winfield (1971), Dickson and Cairns (1972) and Mason (1973) demonstrated the value of artificial substrates in their studies.

Two types of artificial substrates were employed at each station; a quantitative basket designed by Mason _et_ _al_. (1973) and a modified Hester-Dendy multiplate sampler.

The basket substrates consisted of barbeque baskets* 7x12 inches filled with 34, 5.1 cm (2 inch) diameter unglazed porcelain spheres +. Each basket exposes approximately 0.2756 m^2 (2.97 ft^2) of substrate. The modified multiplate samplers consisted of eight plates of tempered hardboard (scored on one side) 7.6 cm (3 in.) square and 0.32 cm (1/8 in.) thick, mounted on a stainless steel eyebolt. The upper 4 plates were separated by spacers 2.5 cm (1 in.) square and 0.32 cm (1/8 in.) thick. The next 3 plates were separated by spacers 2.54 cm (1 in.) square and 0.64 cm (1/4 in.) thick; and the remaining plate was separated by a spacer 2.54 cm (1 in.) square and 1.05 cm (3/8 in.) thick. The total exposed surface area is approximately 0.0929m^2 (1 ft^2).

*Paramount Wire Inc., 1034 Westminster Ave, Alhambra, California.

+Ferro Corporation, Refactories Division, East Liverpool, Ohio.

Four basket and two Hester-Dendy substrates were placed in ecologically comparable habitats at each station (e.g. substrate and current velocity). Substrate placement was as consistant as possible throughout the study. Hilsenhoff (1974) found a greater number of genera collected on artificial substrate in the faster current. All the more common genera, however, were collected in both rapid and slow current. He also found that water depth, in and of itself, is not a factor in establishing insect populations. This agrees with Zillich (1967) that depth is not important if other factors such as current are the same. An effort was made to anchor substrates in both riffle and pool areas in order to collect species indigenous to all habitats. Substrates were anchored by 0.64 cm (1/4 in.) braided nylon rope attached to concrete anchor blocks or steel pitons driven into large river rocks. Hester-Dendy substrates were attached to the side of the baskets with plastic cable ties. Complete transects were not always possible because of anchoring difficulty but an effort was made to include data from both banks. Substrates were placed on a gravel or bedrock bottom, parallel to the current, in approximately one meter of water at normal discharge. Substrates were marked and retrieved by means of a line attached to a plastic buoy. Substrates were collected by a Tutox 46x20 cm bottom net immediately downstream of the substrate, the line was raised and the net placed around the basket in order to avoid loss of any organisms. Organisms thus dislodged were picked from the net and preserved with the samples. Most substrate placement and retrieval necessitated the use of a flat bottom jon boat powered by a 9.5 h.p. outboard engine.

Once retrieved, the samplers were immediately placed in individual wash buckets partially filled with water. Each ball or plate was brushed or washed and returned to the same sampler. All samplers were returned to the same location in the river throughout the year.

Stations were sampled at six week intervals throughout the year dependent upon river discharge and extreme weather conditions. The author is aware that most aquatic insects exhibit an annual turnover. When a species emerges, most of the population is removed from the stream in a period of several days or a few weeks. We are dealing, however, with comparisons of relative biomass (density) and diversity between pre-and post-discharge conditions. An effort was made to consider seasonal emergence in statistical calculations.

A Surber square foot bottom sampler was also used to collect macroinvertebrates in shallow riffle areas. Data gathered by this method was used as a standard with which to assess the sampling efficiency of the artificial substrates. In addition, an effort was made to hand collect benthic macroinvertebrates in all possible habitats within the designated station limits, e.g. rocks in slow, fast shallow and deep water; mud, sand and gravel bottom areas; wood, vegetation, etc. Habitats such as rocks, wood and emergent vegetation were first hand collected--the insect being picked off the substrate and placed in 5% formalin. In riffle areas a kick screen was placed vertically on the bottom and the rocks and gravel above it were kicked-up (agitated) dislodging the insects into the net. This qualitative method supplied information on the kinds of bottom organisms that were not specific to our substrates. The location from which a surber or qualitative sample was collected at a given station varied between collecting dates as the river stage fluctuated.

The samples were washed through a U.S. Standard No. 30 sieve (0.595mm openings), preserved in 0.2% Rose Bengal-5%formalin solution, hand sorted in the laboratory under a 2x scanning lens, counted and recorded as numbers per sampler. Except or oligochaetes, organisms were identified to species whenever possible. The taxonomic treatment of each group will be uniform

throughout the study, and each level of identification was considered as one taxon in determining the total number of taxa in the samples. It is recognized that some oligochaetes and small instars are not retained during sieving. Although admittedly biased for a particular size group, the use of a standard-size sieve permits valid comparisons.

General keys used for the identification of macroinvertebrates were Pennak (1953), Chu (1949), Usinger (1956), Needham and Needham (1973) and Parrish (1968); specific keys included Mason (1973), Smith (1969) and Johannsen (1973) for dipterans; Burks (1953) and Leondard and Leonard (1962) for ephemeropterans; Classen (1931) for plecopterans; Ross (1944) for trichopterans; Brown (1972) for coleopterans; Foster (1972) and Surber and Klemm (1972) for annelids; Kenk (1972) for turbellarians; Holsinger (1972), Hobbs (1972) and Williams (1972) for crustaceans; and Harmon and Berg (1971), Burch (1975) and Burch (1973) for mollusks.

Loss of substrates occurred at all stations at various times as a result of high water and vandalism; such losses complicated statistical analysis. Data from artificial substrates are considered as one continuous series of collections from March 1974 through July 1975. Macroinvertebrate density and diversity were compared between stations so that river segment linearity could be established. The objective was to establish baseline data on which post-discharge conditions could be assessed. All samples taken at a particular station on a collection day were pooled for ease of analysis. Testing for significant differences between samplers was unnecessary as there were no point sources of pollution within the study area. Differences among stations at all transects within a time period were compared using Duncan's multiple range test. Computations were carried out with both written and pre-existing programs. Diversity and redundancy were calculated with the program of Poché (1975). In all statistical tests differences were considered

significant at the 0.95 confidence level.

Diversity indices derived from information theory make it possible to analyze large amounts of information about numbers and kinds of organisms. These indices make it possible to summarize community structure by providing comparable numerical values. Margalef (1961), Patten (1962), Wilhm and Dorris (1967) and Harrel and Dorris (1968) have shown that diversity indices validly denote ecological change. These indices have the advantage of expressing two parameters of the aquatic community as a single value (the number of species in the community and the evenness with which species occur.)

Diversity per individual, $\bar{D}$ represents the average information contributed by individuals to the community. Redundancy, R, represents the measure of dominance of one or more species in the community. Communities can have the same $\bar{D}$ but differ in redundancy. Diversity is equated with the amount of uncertainty which exists regarding the species of an individual selected at random from a population. The more species there are and the more even their representation, the greater the uncertainty and hence, the greater the diversity (Pielou, 1966). It is unlikely that all the species present in a community will be taken in a sampling program because of the many rare species present. When $\bar{D}$ is used, maximum contribution to total diversity will be made by a species that comprises 37% of the sample and the contribution to total diversity by rare species is small.

Maximum diversity exists if each individual belongs to a different species, and minimum diversity exists if all individuals belong to the same species. Thus diversity indices represent the wealth of species. Pollution results in depression in diversity in the biotic community. The value of $\bar{D}$ can vary from zero to any positive number. A value of zero is obtained when all individuals belong to the same species. The maximum value of $\bar{D}$ depends on the number of individuals counted and is obtained when no two

individuals belong to the same species. Values less than 1 are obtained in areas of heavy pollution, values from 1 to 3 are typical of areas of moderate pollution or recovery zones and values exceeding 3 are indicative of clean water conditions. (Wilhm and Dorris, 1968).

Diversity, $\bar{D}$, was computed from the following equations (Harkins and Austin, 1973);

$$\bar{D} = \frac{1}{N}\left(\log_2 N! - \sum_{i=1}^{S} \log_2 n_i!\right)$$

Redundancy was computed from the equation:

$$R = \frac{\sum_{i=1}^{S} \log n_i! - S \log (N/S)!}{\log (N-S+1)! - S \log (N/S)!}$$

where N= total number of organisms

n_i= number of organisms in the i^{th} genera

S= total number of genera

Density or biomass was calculated for each artificial substrate. The number of organisms per m^2 is somewhat misleading as an expression of standing crop and production because of wide variations in the size of organisms, some having a mass as much as 25 to 50 times others. A single large Odonata nymph, for example, may weigh more than 30 small mayfly nymphs. A more significant index is the total ash-free dry weight of organisms per m^2.

Macroinvertebrates were suction-filtered onto glass fiber filter discs and dried to constant weight at 103C° for 1 hour. Discs were weighed and incinerated in a muffle furnace at 550C° for one hour. This final weight was determined to be the ash-free dry weight of each artificial substrate.

Basket substrates filled with drifting organic detritus making it difficult to quantitate organisms on a surface area basis. We considered the inhabitants of each substrate as being itself a population, rather than a sample of something larger.

RESULTS AND DISCUSSION

The following analyses were made on the pooled samples collected at each station: 1) community composition by percent at each station within the study area (Figure 27, Tables 15,16,17,18); 2) taxonomic diversity and density (Figure 28, Tables 12,13,14); 3) community diversity indices (Tables 12,13,14); 4) seasonal occurrence (Tables 23 & 25 and Figure 30). We also compared the efficiency of the various sampling techniques. Results of these analyses for stations and seasons are considered below. Significant differences between the sampling techniques and community structure at each station were tested by one-way analysis of variance. Species lists by station and seasonal occurrence are in appendix D (Tables 10 and 23).

During the predischarge survey, four phyla, 68 families and 176 genera of macroinvertebrates were collected from the study area (Table 10, appendix D). The phylum arthropoda had the most representatives followed by the phyla mollusca, annelida and platyhelminthes, respectively. Orders represented by the greatest number of genera were Diptera (50), Odonata (27), Coleoptera (19), and Trichoptera (16). Only 36 of the 175 genera collected in the study area (20%) were common to all stations (Table 11). The Diptera were more evenly distributed throughout the study area than the other orders. Station 001 had more kinds with 105 or 59% of the total kinds collected in the study area (Table 28). Stations 002-006 had 101,91,83,101 and 95 kinds or 57%,47%,50%,57% and 56% respectively of all kinds collected (Table 10). Station 004 is significantly less diverse (fewer genera) than the other 5 stations. Station 004 is principally a deep pool of relatively slow current velocity ($\leqslant .2$M/sec) and a small riffle area.

Percent composition or relative importance of the principal orders, Trichoptera, Ephemeroptera, Diptera and Annelida, was approximately linear downstream indicating consistent water quality throughout the study area. There was a sharp decline in trichoptera density with a corresponding increase in ephemeroptera at Station 004 (Figure 27). This variation can probably be attributed to the decreased flow velocity at this station. Trichoptera composed a greater percentage of the total population at Station 006 than at any other station probably due to a greater flow velocity ($\geq$0.5 M/sec).

The basket type sampler was superior in collecting both more numbers and more kinds of organisms than either the Hester-Dendy (HD) artificial substrate or the Surber bottom sampling technique (Tables 12,13 & 14). The mean number of individuals and mean number of kinds collected from baskets was 489 and 16.6 respectively (Table 12). HD substrates and Surber sampling collected a comparable number of individuals $\bar{x}$=219 and 245 respectively and $\bar{x}$=15.8 and 13.2 respectively (Tables 13 and 14). The basket sampler produced significantly more (10x) biomass per sampler than either the HD or Surber sampler (Tables 12,13 &14) although they exposed 3x the surface area.

Mean diversity per individual, $\bar{D}$, was comparable between basket samplers (x=2.464) (Tables 12 and 13). Redundancy per individual was also comparable between these samplers, .3567 and .3897 respectively (Tables 12 and 13). Surber sampling, however, provided a mean diversity per individual of 2.215 and a mean redundancy per individual of .4189 (Table 14). The artificial substrates collected a greater diversity of organisms because drifting organic detritus gathers in them and provides a rich and varied diet for the macroinvertebrates.

Considerable variation in numbers of individuals collected has been found to occur in this and other studies using artificial substrates.

Obtaining reliable macroinvertebrate samples from large swift rivers like the James is very difficult (Hynes, 1970; Edmundson and Winberg, 1971; Weber, 1973). Uneven distribution of organisms and dissimilarity of habitats are the principal problems.

The principal orders collected within the study area by all methods and their frequency of occurrence are listed in Table 15. The trichoptera comprised the largest portion of the macrobenthos collected (52%). Other principal orders were oligochaetes (12%), ephemeroptera (11%), diptera (8%), turbellaria (7%), gastropods (4%), and odonata nymphs (1%).

Each collecting method was found to be specific for certain kinds and relative numbers of macroinvertebrates. Surber sampling collected the greatest porportion of trichoptera (60%) whereas the basket and Hester-Dendy artificial substrates collected 52 and 46% respectively. Surber sampling also contributed the greatest percentage of diptera (21%) as opposed to both types of artificial substrates at 8%. The H-D substrates were more efficient in collecting ephemeroptera with 20%, followed by the basket (10%) and Surber sampler (6%). The basket sampler was most efficient in collecting both oligochaetes and turbellaria (12 and 8% respectively) than the other two methods (Tables 16,17 and 18).

Basket samplers collected 160 kinds or 92% of the 175 total kinds collected. The H-D type substrates were significantly less efficient, collecting only 60 and 62 (34 and 35%) kinds, respectively. The common kinds appearing at all stations were also the kinds collected most frequently by all 3 sampling methods. The H-D substrate and the Surber sampler did not offer as large a surface area as the basket and there were not as many replications. Only 4 additional genera were collected by qualitative sampling (Table 18) and all were unique to station 006.

One-way analysis of variance, completely randomized design, was used

to compare the efficiency of the three sampling methods at each station. The Surber sampler did not differ significantly in density (number/m^2), kinds or biomass/m^2 between stations. Surber samples were taken only in the spring, summer and fall in normal to low-flow conditions and only in riffle areas less than one foot deep.

Hester-Dendy substrates produced comparable kinds and biomass at each station but the density (number/m^2) differed significantly (f=3.07,df=5,20) between stations. Table 20 represents the results of Duncan's Multiple Range test which shows that the mean number of organisms collected by HD substrates at station 006 was significantly greater than Station 001 and 002 (p=.05).

The basket substrates also collected comparable numbers of kinds at each station but the mean diversity (number/basket) and mean biomass differed significantly between stations. Duncan's Multiple Range test showed that the baskets collected a significantly (p=.05) greater number of macroinvertebrates at station 006 (table 21). This increase in density can be attributed to the faster current at 006 (.5m/sec) and possibly to the influence of the Tye River tributary. Trichoptera composed a greater proportion (71%) of the total fauna collected at 006 than at any other station (Table 15, Figure 27). Total mean biomass collected by baskets was significantly greater at station 003 illustrated by Duncan's Multiple Range test (Table 22). The river is wide and shallow at 003 providing a good habitat for pelecypods and gastropods which contribute to a greater biomass.

The diversity index is used to describe longitudinal variation in community structure of benthic macroinvertebrates through the study area. Analysis of variance did not show a significant difference in $\bar{D}$ per individual between stations (F=1.15 with df=5,175) or in redundancy per individual at each station (f=1.11 with df=5,173) (Figure 29).

It appears that the biological communities doe not vary significantly through the segment of the river under study. This lack of variation can be attributed to a linear river profile and homogeneous water quality.

Diversity per individual, $\overline{D}$, ranged from .602 (10 kinds and 421 organisms) at Station 005 in September to 3.718 (25 kinds and 136 organisms) at Station 003 in April. Wilhm and Dorris (1968) stated that $\overline{D}$ values less than 1 are obtained in areas of heavy pollution, means from 1 to 3 are typical of areas of moderate pollution or recovery zones and values exceeding 3 are indicative of clean water conditions. Only 36 of the 179 samples (20%) taken within the study area had a diversity value of 3.0 or more (Table 24). Station 003 had the largest percentage of samples with $\overline{D}$ greater than or equal to 3.0 (38%) whereas Station 001 had the smallest percentage (8%). The percentage of samples less than or equal to 3.0 taken at other stations were: Station 002=27%, Station 004=9%, Station 005=13%; and Station 006=27%.

Only 4 macroinvertebrate samples (2%) taken within the study area had $\overline{D}$ 1.0. The majority of the samples (78%) taken within the study area had $\overline{D}$ values between 1.0 and 3.0. The $\overline{D}$ values in this portion of the James are more indicative of a recovery zone rather than of organic enrichment because there are no significant point-sources of pollution within the river segment or immediately above it.

Table 23 presents the occurrence of all macroinvertebrates on a monthly basis. Representatives of only 10 genera were collected in all months (seasons) within the study area. These were *Physa sp.*and *Sphaerium sp.*and *Corbicula monilensis* (Molluska);*Stenonema sp.* (Ephemeroptera); *Cricotopus sp.*, *Simulium sp.* and *Chaoborus sp.* (Diptera); *Cheumatopsyche sp.*, *Hydropsyche sp.* and *Neureclipses sp.* (Trichoptera). It is probably that additional genera would have been collected in all months if all stations had been sampled on a monthly basis.

Trichoptera always composed the largest percentage of macroinvertebrates collected each month except in March when oligochaetes composed with largest percentage (Table 24) (only stations 001 and 002 were sampled in March). The trichoptera were most abundant and comprised the largest portion of the communtiy from June through December (45%)(Table 24). The dominant trichopterans, *Cheumatopsyche*, *Hydropsyche* and *Neureclipsis* were abundant throughout the year. The other kinds of trichoptera were collected randomly throughout the year.

Both diptera and oligochaetes comprised the larger proportion of the macroinvertebrate community from January through May. (Table 24) Although a few plecoptera (stoneflies) were found year around they comprised 11% of all macroinvertebrates collected in January. The plecopteran *Tarniopteryx* and the dipteran *Cricotopus* showed pronounced peaks during winter and early spring. Ephemeropterans (mayflies) were significantly more abundant from July through October (Table 24). *Stenonema sp.* was the most abundant mayfly and was collected throughout the year. *Baetis sp.*, *Pseudocloen sp.*, *Isonychia sp.* and *Tricorythodes sp.* were most abundant in the late spring, summer and early fall months (Table 23). Although some macroinvertebrates occurred throughout the year, most were seasonally abundant in summer and early fall.

An increase in the relative composition of the turbellarian population from May through December was proportional to a decrease in the oligochaete population (Table 25). Odonates (dragonflies and damselflies), coleopterans (beetles) and crustaceans (crayfish, isopods, and amphipods) did not compose a significant proportion of the macroinvertebrate community in any month nor did the percentage composition of these populations vary seasonaly (Table 24).

The greatest mean number of organisms per sample was collected in June (1,012) with most sampling done at station 006. This large mean can be

attributed to the dense caddisfly population at station 006 (Figure 1). Mean monthly numbers collected per sample declined throughout the rest of the twelve-month period to 102.5 ($\bar{x}$) organisms in January (Table 25). Monthly means were dependent upon which stations were sampled in a particular month. It was not possible to sample all stations in each month due to the rotating, six week interval sampling schedule.

The mean number of kinds of macroinvertebrates per sample was largest in May, June and July (17) and declined steadily through January (12) (Table 25, Figure 30). Mean biomass (ash-free weight) per sample was also largest during June (0.2456) (g) decreasing to 0.0116 g during March (Figure 30). June appears to be the time of greatest macroinvertebrate production in this portion of the James.

Those macroinvertebrate samples taken in December had the highest mean diversity per individual ($\bar{D}$= 2.82) whereas those in March had the lowest ($\bar{D}$=2.015) (Table 25). Although $\bar{D}$ did not vary significantly between stations it does appear that the mean monthly diversity was influenced by the stations where the samples were taken. Redundancy was highest in March (0.5232) and lowest in December (0.2217) (Table 25). A high redundancy indicates a preponderance of one or a few organisms. It appears that December, with the lowest mean temperature, had the best water quality as measured by biological methods.

Since temperature controls the rate of biological processes, it is used to divide the macroinvertebrate data into seasons. The mean water temperature on samples days in April through October, the most biologically productive period, was 14°C. The Student's t-test does not show a significant difference ($p=.05$) between the summer season mean diversity per individual (2.43) and the winter season mean $\bar{D}$ (2.37). Mean redundancy was also

higher during the summer months, r=.394 vs r=.350, reflecting the preponderance of the trichopterans *Cheumatopsyche*, *Hydropsyche*, and *Neureclipsis*. Mean redundancy did not differ significantly between the two seasons ($p=.05$).

It was possible to test for significant seasonal differences only between stations 001 and 002 because the others were sampled infrequently during the winter months. The Student's t-test showed that the mean $\bar{D}$ and redundancy did not differ significantly between these stations in either the summer or winter seasons.

Indicator Organisms

Community structure studies describe the composition of a community but don't tell us what organisms compose the community. Simmons and Reed (1973) stated that community studies are not a panacea for the interpretation of the response of biological communities to stress conditions. They go on to say that "there are many factors which enhance community diversity, such as substrate morphology, predation, competition, evolutionary time, stability of chemical and physical conditions, etc." At present biologists have a poor understanding of the factors which regulate diversity (Warren, 1971). Warren (1971) pointed out "diversity indexes are but a tool and do not have meaning in and of themselves."

The idea that certain species can be used to indicate certain types of aquatic environmental conditions is well established. The presence of a species indicates that the water quality is suitable for that species. Some of the environmental requirements are known for many species. The presence of a species indicates that certain minimal conditions have been met, but its absence is less revealing of environmental conditions.

The advantages and disadvantages of indicator organisms have been documented elsewhere (Copeland, 1966; Oglesby,1966; Stein and Denison,1966; Wass, 1966 and Cairns,1974). These authors appeared to believe that conclusions should not be based on the presence, absence or proportion of indicator organisms alone, but that these factors are useful supplementary observations. It is probably more valid to speak of indicator assemblages of species (insects or other groups) or indicator communities, but at present our knowledge is not sufficient to define these units in the invertebrates. The presence or absence of a species can be determined by such factors as: 1) its presence or absence in the species pool available for colonizing the area studied;

2) the season in which the collection is made; 3) flow conditions at the time of study; and 4) chance (Hart and Fuller, 1974).

In this section of river, many species were abundant which are considered both tolerant and intolerant of stress. Cairns and Dickson (1971) and Mason et al.(1970) listed Plecoptera, Trichoptera, Ephemeroptera and Megaloptera as pollution-sensitive or intolerant organisms. These taxa are well represented among the invertebrates at all stations. Other dominant taxa include the Diptera (particularly Chironomidae and Simulidae) some of which are generally considered moderately tolerant of stress.

Without a doubt, this section of the James can be considered a Trichopteran habitat. This order contains species thought to be sensitive to different forms of pollutants (Gaufin, 1952; Gaufin, 1958; Kemp, 1966; and Mackenthun, 1966). The four dominant genera of Trichoptera encountered were Cheumatopsyche, Hydropsyche, Macronemum and Neureclipsis. The relationship of abundance among the genera of caddisflies depended on current, bottom substrate characteristics and seasonality. These net builders as a whole seem to be tolerant of mild organic loading, but not toxic pollutants or suspended inorganic particles (Hynes, 1970). Cheumatopsyche is generally considered to be a facultative species (Weber, 1973).

Large populations of Hydropsyche, Cheumatopsyche, and Simulium (Diptera) were present throughout the year. The success of these species was apparently due to limited predator pressure, abundance of food, lack of interspecific competition, etc. Patrick (1970) noted similar population increases by blackfly larvae when carnivorous mayfly and stonefly species were absent.

Ephemeroptera are also abundant in this portion of the James. These are considered to be the most truly aquatic insects of all the insects that have adapted to the aquatic environment. The mayflies have generally been considered to be very sensitive to pollutants--in most cases meaning organic loading,

but Hart and Fuller (1974) stated that, as a generality, this is not true. They found Stenonema, the most abundant genus in this section of the James, in situations inimical to sensitive species. Baetis and Tricorythodes, Caenis and Pseudocloeon were also seasonally abundant, reaching their greatest density in late summer and early fall. Baetis is considered to be intolerant of stress whereas the other mayflies can be considered facultative.

The Plecoptera are perhaps the most pollution-sensitive of the macroinvertebrates. Only six genera were found within the study area (Table 10). All six are listed as winter stoneflies and they were collected only in the winter and early spring months when the water is colder and DO levels are consistently higher (Frison, 1929).

The principal representatives of the Diptera were the families Chironomidae and Simuliidae. Chironomids have representatives tolerant of many chemical extremes. Members of the subfamily Chironominae possess hemoglobin which enables them to survive periods of low DO better than those which lack it. Chironomid numbers undergo great fluctuations. Many species produce several generations a year and a river may be rapidly repopulated from a small residual population. The larvae of both the Chironomidae and Simuliidae are truly aquatic and breathe by cutaneous respiration or by means of blood gills. Generally these families are considered to be facultative with respect to pollution.

This section of the James River supports a diverse and seasonally dense population of mollusks. Our collections included two of the five classes of mollusks, namely: Gastropoda and Pelycypoda. Gastropods were most abundant in the fall and made up a significant portion of the biomass of the samples collected. The pill clams were abundant in the summer and fall whereas the larger mussels could be collected in all seasons. Simmons and Reed (1973) found that the mollusks are a more sensitive component of the macrobenthos

than some insect orders. Hynes (1962) commented that the presence of mollusks in streams is favored by organic enrichment. Mackie and Qadri (1973) found mollusks, including unionid mussels, limited by an excess of potassium ions which is commonly produced by pulp and paper mills.

The presence of unusually large populations of mussels can be indicative of pollution only where there is moderate organic enrichment (Hart and Fuller, 1974). The pill clam Sphaerium striatum, collected in large numbers from this section of the James, tolerates organic enrichment. Grantham (1969) listed a number of authorities who have thought of the Sphaeriidae as tolerant of polluted, nearly septic conditions.

The Asiatic clam, Corbicula manilensis became established in this portion of the James during the second year of the pre-discharge study. This clam was recently reported in the tidal James by Diaz (1974). Hart and Fuller (1974) describe the species as itself a pollutant in that it competes with the native fauna for space. It has the ability to exploit virtually every substrate. This species has been found at all the stations and its density is steadily increasing.

There are two subclasses of Gastropoda common to this section of the James River. One, Prosobranchia, is represented by the families Hydrobiidae, Viviparidae, Pleuroceridae and Valvatidae. The other subclass, Pulmonata, is represented by the families Physidae, Lymnaeidae, Planorbidae, and Ancylidae (Table 10). The Pulmonates are most resistant to stress but almost every common species has been found in polluted environments (Hart and Fuller, 1974). Weber (1971) lists the air-breathing snails, Physa and Planorbis, as tolerant of oxygen depletion. Both are common within the study section.

Oligochaete worms (sludgeworms), principally naideds and tubificids which are characteristic of enriched conditions, occurred in samples collected

at all stations. The tubificids are detritus feeders and rely mainly on organic particles within the substrate (Hynes, 1962). Naidid worms, however, are essentially inhabitants of soft substrates in the depositing region of rivers (Hynes, 1960) and where the environment becomes enriched by organic material large populations occur (Learner _et al_., 1971).

Brinkhurst (1974) stated that Oligochaetes and some other soft-bodied forms (flatworms, mollusks and leeches)are more tolerant of some toxic pollutants than are arthropods but are sensitive to anything that reduces bacterial activity. Their ability to withstand oxygen depletion is an essential adaptation to their niche. Brinkhurst also states that the abundance of worms relative to other organisms as well as the relative abundance of various species of worms may be of interest.

Oligochaetes comprised the second largest percentage of individuals collected at station 001 (22%) and the smallest percentage of total individuals at station 006 (2%) (Table 15). The large difference in percent composition of the macroinvertebrate community can be accounted for by the greater current velocity at station 006 and the possible increase in water quality due to the dilution effect of the Tye River. Basket samplers collected oligochaetes more readily than the other methods due to the detritus which collected within them (Tables 16,17,18).

Oligochaetes did not comprise a dominant proportion of any samples collected. It is important to realize that these worms that are indicative of enriched conditions can be present in clean environments, though their microhabitats therein may be naturally polluted by leaves or other rotting organic matter.

Another soft-bodied form, flatworms or turbellarians, also constituted a significant proportion of the macroinvertebrates. Planarians require well-

oxygenated water although some species tolerate DO levels of less than 2 mg/l (Abbott, 1960). Organic pollution is detrimental to planarians, chiefly on account of two factors: the depression of the D.O. content in the water caused by oxidative processes and the metabolism of microorganisms and the presence of toxic intermediary and end products of putrefaction.

While there are exceptions, it is generally true that an association of mayflies, stoneflies and caddisflies in a stream denotes clean water conditions, and their absence means the presence of pollution of a low oxygen supply or both, if the physical nature of the habitat is otherwise suitable (Gaufin, 1973).

As shown in Table 15, the majority (72%) of the bottom organisms collected belonged to the 5 insect orders, Ephemeroptera, Trichoptera, Diptera, Odonta and Coleoptera. The trichopterans and dipterans accounted for 60% of all specimens collected. Kaesler et al., (1973) found that in terms of new information provided, it is unlikely that the study of leeches, amphipods, decapods, bivalves and others besides the insects and snails was worth the effort.

Since tolerant species may be found in both clean and degraded habitats, a simple record of their presence or absence has little significance. Therefore, the indicator organism technique can provide evidence of clean water condition only if intolerant organisms are collected. Clean water environments support communities having large numbers of species with no individual species present in overwhelming abundance. This could be considered to be generally true for this portion of the James although an abundance of the facultative caddisflies in most collections indicated slight organic enrichment. None of the stations had macroinvertebrate communities composed entirely of clean water representatives.

SUMMARY AND CONCLUSIONS

An intensive macroinvertebrate investigation of the James River in the vicinity of Riverville, Virginia, was undertaken in an effort to establish baseline data on which to assess the effects of the Virginia Fibre Corporations' effluent. Samples were collected from six ecologically comparable stations at six-week intervals by means of two types of artificial substrate and Surber bottom sampling.

Four phyla, 68 families and 176 genera were identified in the macrobenthos samples taken from the James River. The insects were the most abundant and of these the caddisflies (Trichptera), a group usually associated with clean or mildly polluted waters, were most numerous. Relatively fewer stoneflies (Plecoptera), more often found in unpolluted waters, appeared in our samples, and the enrichment indicators (mollusks, oligochaetes and flatworms) were plentiful when other factors of flow, substrate and season favored their growth. Organisms thought to be sensitive to both organic pollution and industrial toxins also turned up in our collections.

To a degree, the collecting method itself influenced the composition of the collection. Basket substrates accumulated more individual organisms than did either the Hester-Dendy substrates or the Surber Square Foot Sampler, and the latter technique provided samples which had a lower value for diversity than did either artificial substrate. The Surber Sampler was unique in that it captured genera that were absent from the artificial substrates and it had the added advantage of immunity to loss by vandalism and high water. Such losses of artificial substrates created data gaps which made statistical analysis difficult.

All six stations had approximately the same faunal composition, though there were somewhat more caddisflies at station 006 where the current was

faster. While there were density changes in all the stations and most of the macrobenthic species were more abundant during the warmer months than in the winter, their general composition remained the same throughout the year and community diversity did not differ significantly between the cold and warm seasons.

Levels of dissolved oxygen and the degree of oxygen saturation and the concentration of dissolved nutrients measured in this section suggest that only moderate organic loading occurs above the study area. The physical and chemical characteristics of the water in this section of the James appears conducive to a high diversity of organisms, yet diversity indexes were relatively low indicating that the stress on this community is probably caused by organic pollution. Unfortunately, there is no easily obtained chemical, physical, or biological parameter that can be quantitatively measured to indicate exclusively that organic pollution exists. The water through this section, although organically enriched is undergoing recovery from the heavy loading it receives at Lynchburg. Macroinvertebrate community structure can be considered the same at each station thereby indicating linear water quality through the study segment.

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APPENDIX A

Physical - Chemical Data

TABLE 3.

STATISTICAL VALUES FOR MEASURED PARAMETERS, ALL DATES, STATION 001

Parameter	N	Mean	S.D.	$SE\overline{X}$	Coeff. of Variation
Alkalinity	59	72.25	16.47	2.14	0.23
BOD	55	2.53	1.28	0.17	0.49
Chloride	22	13.22	6.88	1.47	0.52
Color	71	43.03	19.38	2.80	0.45
DO	69	10.22	1.68	0.20	0.16
% Saturation	70	100.73	15.04	1.80	0.15
FC	67	484.61	856.90	104.69	1.77
pH	71	7.49	0.47	0.06	0.06
Sodium	22	8.76	3.28	0.70	0.37
Solids					
Settleable	22	$\geq$0.1	-	-	-
Suspended	22	12.31	9.67	2.06	0.79
Volatile	22	5.22	1.84	0.39	0.35
SC	71	222.70	67.20	7.97	0.30
Sulfates	26	18.86	5.52	1.08	0.29
Temp.	72	16.15	8.34	0.98	0.52
TKN	18	3.42	4.89	1.15	1.43
Total PO_4	23	0.10	0.06	0.01	0.64
Turbidity	64	11.63	22.17	2.77	1.91
COD	5	16.70	7.84	3.51	0.47

STATISTICAL VALUES FOR MEASURED PARAMETERS, ALL DATES, STATION 002

Parameter	N	Mean	S.D.	SE$\overline{X}$	Coeff. of Variation
Alkalinity	62	72.58	16.59	2.11	0.23
BOD	58	2.61	1.32	0.17	0.51
Chloride	22	12.40	6.91	1.47	0.56
Color	73	43.49	20.46	2.39	0.47
DO	73	10.20	1.74	0.20	0.17
% Saturation	74	99.70	13.01	1.51	0.13
FC	69	397.64	657.25	79.12	1.65
pH	73	7.45	0.43	0.05	0.06
Sodium	22	8.52	3.69	0.79	0.43
Solids					
Settleable	23	$\geq$0.1	-	-	-
Suspended	23	13.18	12.13	2.53	0.92
Volatile	23	5.26	2.37	0.49	0.45
SC	73	222.08	64.13	7.51	0.29
Sulfates	26	18.00	5.46	1.07	0.30
Temp.	74	15.94	8.38	0.97	0.53
Total PO_4	22	00.095	0.06	0.01	0.65
Turbidity	68	17.12	29.95	3.63	1.75
COD	5	19.28	8.52	3.81	0.44

STATISTICAL VALUES FOR MEASURED PARAMETERS, ALL DATES, STATION 003

Parameter	N	Mean	S.D.	$SE\bar{X}$	Coeff. of Variation
Alkalinity	64	70.96	16.94	2.12	0.24
BOD	62	2.51	0.89	0.11	0.35
Chloride	22	11.63	7.15	1.52	0.61
Color	77	43.50	10.39	2.32	0.47
DO	76	10.24	1.70	0.19	0.17
% Saturation	77	100.72	13.16	1.50	0.13
FC	72	336.29	591.16	69.67	1.76
pH	77	7.49	0.49	0.06	0.06
Sodium	22	8.84	3.74	0.80	0.42
Solids					
Settleable	23	≥0.1	-	-	-
Suspended	23	16.67	15.05	3.14	0.90
Volatile	23	5.73	2.42	0.51	0.42
SC	77	217.44	64.83	7.38	0.30
Sulfates	26	17.54	5.26	1.03	0.30
Temp.	78	15.85	8.11	0.92	0.51
TKN	18	3.71	5.09	1.20	1.37
Total PO_4	23	0.088	0.08	0.02	0.98
Turbidity	80	15.89	29.66	3.54	1.87
COD	5	13.17	7.37	3.29	0.56

STATISTICAL VALUES FOR MEASURED PARAMETERS, ALL DATES, STATION 004

Parameter	N	Mean	S.D.	SE$\bar{X}$	Coeff. of Variation
Alkalinity	64	70.97	16.60	2.08	0.23
BOD	61	2.50	1.32	0.17	0.53
Chloride	22	11.79	7.08	1.51	0.60
Color	77	44.45	20.71	2.36	0.47
DO	76	10.36	1.66	0.19	0.16
% Saturation	77	101.90	12.88	1.47	0.13
FC	71	300.75	538.64	63.92	1.79
pH	76	7.42	0.99	0.11	0.13
Sodium	22	8.99	4.28	0.91	0.48
Solids					
Settleable	23	≥ 0.1	-	-	-
Suspended	23	17.71	12.74	2.66	0.72
Volatile	23	6.50	3.60	0.75	0.55
SC	76	217.50	63.82	7.32	0.29
Sulfates	26	18.80	6.13	1.23	0.33
Temp.	77	16.00	8.05	0.92	0.50
TKN	17	2.87	4.14	1.00	1.44
Total PO_4	22	0.097	0.06	0.01	0.66
Turbidity	69	16.70	33.89	4.08	2.03
COD	5	14.65	7.43	3.32	0.51

STATISTICAL VALUES FOR MEASURED PARAMETERS, ALL DATES, STATION 005

Parameter	N	Mean	S.D.	SE$\bar{X}$	Coeff. of Variation
Alkalinity	58	70.72	15.96	2.10	0.23
BOD	57	2.22	0.82	0.11	0.37
Chloride	21	11.88	7.21	1.57	0.61
Color	68	43.01	21.00	2.55	0.49
DO	68	9.74	1.81	0.22	0.19
% Saturation	69	97.12	11.92	1.44	0.12
FC	75	318.60	663.81	82.34	2.08
pH	68	7.51	0.43	0.05	0.06
Sodium	22	8.83	3.62	0.77	0.41
Solids					
Settleable	12	≥0.1	-	-	-
Suspended	23	19.00	14.09	2.94	0.74
Volatile	23	6.49	3.77	0.79	0.58
SC	68	219.66	60.12	7.29	0.27
Sulfates	25	17.89	4.96	0.99	0.28
Temp.	69	16.89	7.54	0.91	0.45
TKN	18	3.92	6.38	1.50	1.63
Total PO_4	22	-.09	0.05	0.01	0.56
Turbidity	63	16.95	37.71	4.75	2.22
COD	5	14.63	7.26	3.25	0.50

STATISTICAL VALUES FOR MEASURED PARAMETERS, ALL DATES, STATION 006

Parameter	N	Mean	S.D.	SE$\bar{X}$	Coeff. of Variation
Alkalinity	63	61.50	14.05	1.77	0.23
BOD	61	2.51	1.35	0.17	0.54
Chloride	22	10.03	5.59	1.10	0.56
Color	75	43.30	19.49	2.25	0.45
DO	74	0.00	1.82	0.21	0.18
% Saturation	75	96.96	10.47	1.21	0.11
FC	70	325.43	623.59	74.53	1.92
pH	75	7.41	0.41	0.05	0.06
Sodium	22	7.96	2.54	0.54	0.32
Solids					
Settleable	23	≥0.1	-	-	-
Suspended	23	28.77	43.36	9.04	1.51
Volatile	23	7.78	7.15	1.49	0.92
SC	75	185.85	53.48	6.17	0.29
Sulfates	26	17.07	5.11	1.00	0.30
Temp.	76	15.66	7.81	0.896	0.498
TKN	18	4.48	6.93	1.63	1.55
Total PO_4	22	0.11	0.087	0.018	0.78
Turbidity	68	20.06	45.26	5.49	2.26
COD	5	13.62	9.85	4.40	0.72

Appendix B. Diurnal variations in temperature, dissolved oxygen and solar radiation data averaged on a ½ hour basis for selected dates. This data was recorded by _in-situ_ sensing and recording instruments located at Riverville, Virginia (1.6 km below the VFC discharge)

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  TEMPERATURE  OXYGEN        SATURATION     RADIATION        TIME
  25.4200       7.7100        7.7989        0.0000        0.0000
  25.3100       7.5900        7.8149       -0.0000         .5000
  25.1800       7.5100        7.8331       -0.0000        1.0000
  25.1400       7.6200        7.8397       -0.0000        1.5000
  25.1700       7.8500        7.8353       -0.0000        2.0000
  25.2600       8.0600        7.8222       -0.0000        2.5000
  25.2600       8.2100        7.8222       -0.0000        3.0000
  25.2200       8.2200        7.8280       -0.0000        3.5000
  25.1200       8.1500        7.8426       -0.0000        4.0000
  25.0000       8.0400        7.8603       -0.0000        4.5000
  24.9100       7.9600        7.8735       -0.0000        5.0000
  24.8300       7.8800        7.8853       -0.0000        5.5000
  24.7500       7.8100        7.8972       -0.0000        6.0000
  24.7000       7.7600        7.9046       -0.0000        6.5000
  24.6400       7.7200        7.9135        0.0000        7.0000
  24.5600       7.7200        7.9255         .0300        7.5000
  24.5500       7.7100        7.9270         .0900        8.0000
  24.5500       7.7400        7.9270         .1900        8.5000
  24.5500       7.8300        7.9270         .3000        9.0000
  24.7300       8.0400        7.9002         .7300        9.5000
  24.8200       8.2500        7.8868         .7600       10.0000
  24.9300       8.4100        7.8706         .8200       10.5000
  25.0400       8.6300        7.8544         .9000       11.0000
  25.1300       8.8300        7.8412        1.0500       11.5000
  25.3100       9.0500        7.8149        1.0300       12.0000
  25.3700       9.2200        7.8061         .7400       12.5000
  25.4700       9.5000        7.7916         .9300       13.0000
  25.7500       9.7800        7.7513        1.2400       13.5000
  25.8200       9.9200        7.7413        1.0400       14.0000
  25.9400      10.0800        7.7241        1.0900       14.5000
  26.0900      10.2500        7.7028        1.2400       15.0000
  26.1800      10.3500        7.6901        1.0900       15.5000
  26.1800      10.4500        7.6901         .5900       16.0000
  26.3300      10.4800        7.6690         .7000       16.5000
  26.4000      10.5500        7.6592         .6500       17.0000
  26.4400      10.6100        7.6537         .7000       17.5000
  26.4400      10.5500        7.6537         .4200       18.0000
  26.4800      10.4700        7.6481         .3000       18.5000
  26.4700      10.4300        7.6495         .2000       19.0000
  26.5100      10.3000        7.6439         .0800       19.5000
  26.4700      10.1000        7.6495         .0500       20.0000
  26.4000       9.8700        7.6592         .0300       20.5000
  26.3600       9.6100        7.6648         .0300       21.0000
  26.2900       9.4200        7.6747         .0200       21.5000
  26.2000       9.1900        7.6873         .0200       22.0000
  26.1400       8.8500        7.6958         .0100       22.5000
  26.0000       8.4500        7.7156         .0100       23.0000
  25.9200       8.1800        7.7270         .0100       23.5000
  25.7800       8.1700        7.7470        0.0000       24.0000

     °C            mg/l          mg/l       langleys/hour
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 TEMPERATURE   OXYGEN          SATURATION     RADIATION       TIME
  25.7800       8.1300          7.7470         0.0000         0.0000
  25.6300       7.9200          7.7685         0.0000          .5000
  25.5100       7.8600          7.7858         0.0000         1.0000
  25.4500       8.0800          7.7937         0.0000         1.5000
  25.5400       8.3500          7.7815         0.0000         2.0000
  25.5000       8.5300          7.7757        -0.0000         2.5000
  25.5400       8.7400          7.7815         0.0000         3.0000
  25.5100       8.7200          7.7858         0.0000         3.5000
  25.4200       8.5500          7.7985         0.0000         4.0000
  25.3300       8.5300          7.8120         0.0000         4.5000
  25.2600       8.4100          7.8222         0.0000         5.0000
  25.1800       8.3300          7.8338         0.0000         5.5000
  25.0900       8.2200          7.8470         0.0000         6.0000
  25.0600       8.1600          7.8514         0.0000         6.5000
  25.0400       8.1900          7.8544          .0100         7.0000
  25.0100       8.0600          7.8590          .0700         7.5000
  24.9900       8.0600          7.8617          .1000         8.0000
  24.9600       8.0600          7.8661          .1300         8.5000
  25.0000       8.1900          7.8603          .2700         9.0000
  25.1700       8.2900          7.8353          .6200         9.5000
  25.2000       8.4100          7.8309          .4900        10.0000
  25.2200       8.6000          7.8280          .5300        10.5000
  25.3300       8.7700          7.8120          .5600        11.0000
  25.3900       9.0000          7.8032          .7000        11.5000
  25.5900       9.3300          7.7743          .8200        12.0000
  25.6200       9.3600          7.7700          .7200        12.5000
  25.7000       9.5500          7.7585          .8500        13.0000
  25.7300       9.7200          7.7542          .5500        13.5000
  25.8800       9.8000          7.7327          .8200        14.0000
  26.1000      10.1400          7.7014         1.1200        14.5000
  26.1500      10.2600          7.6944          .7900        15.0000
  26.3100      10.5000          7.6718          .6300        15.5000
  26.6100      10.8200          7.6300         1.2100        16.0000
  26.7800      10.9200          7.6066          .8000        16.5000
  26.8700      10.9300          7.5942          .7500        17.0000
  26.9900      10.9700          7.5778          .6700        17.5000
  27.1000      10.8800          7.5629          .4900        18.0000
  27.1700      10.7000          7.5534          .3500        18.5000
  27.1700      10.5100          7.5534          .2300        19.0000
  27.1400      10.3800          7.5575          .1400        19.5000
  27.1300      10.1600          7.5590          .0700        20.0000
  27.1200       9.9200          7.5602          .0300        20.5000
  27.0600       9.7600          7.5685          .0200        21.0000
  27.0000       9.4900          7.5765          .0100        21.5000
  26.9500       9.2000          7.5835          .0100        22.0000
  26.8700       8.9200          7.5942          .0100        22.5000
  26.7800       8.6700          7.6066          .0100        23.0000
  26.6900       8.4500          7.6190         0.0000        23.5000
  26.5600       8.1400          7.6371         0.0000        24.0000

    °C            mg/l            mg/l       langleys/hour
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 TEMPERATURE   OXYGEN          SATURATION     RADIATION        TIME
 26.5600        8.1400          7.6370         0.0000          0.0000
 26.3800        7.9400          7.6620        -0.0000           .5000
 26.2700        7.8100          7.6775        -0.0000          1.0000
 26.1500        7.7400          7.6944        -0.0000          1.5000
 26.0100        7.6500          7.7142        -0.0000          2.0000
 25.8900        7.6200          7.7313        -0.0000          2.5000
 25.8500        7.7400          7.7370        -0.0000          3.0000
 25.8500        7.9400          7.7370        -0.0000          3.5000
 25.8200        8.1500          7.7413         0.0000          4.0000
 25.8900        8.2900          7.7313         0.0000          4.5000
 25.9000        8.3700          7.7298         0.0000          5.0000
 25.9000        8.3900          7.7298         0.0000          5.5000
 25.8900        8.3500          7.7313         0.0000          6.0000
 25.8600        8.2400          7.7355         0.0000          6.5000
 25.7700        8.1500          7.7484          .0100          7.0000
 25.7000        8.0800          7.7585          .0300          7.5000
 25.6200        7.9900          7.7700          .0600          8.0000
 25.5900        7.9500          7.7743          .1200          8.5000
 25.5700        7.9300          7.7772          .1600          9.0000
 25.5700        7.9600          7.7772          .2200          9.5000
 25.5600        8.1000          7.7757          .3500         10.0000
 25.6600        8.3600          7.7642          .7500         10.5000
 25.8600        8.7100          7.7355          .8900         11.0000
 26.0500        9.0000          7.7085         1.0600         11.5000
 26.2600        9.4200          7.6789         1.2200         12.0000
 26.5400        9.7200          7.6397         1.3400         12.5000
 26.7000       10.0300          7.6176         1.3600         13.0000
 27.0000       10.6400          7.5765         1.6500         13.5000
 27.1400       11.0800          7.5575         1.2100         14.0000
 27.3300       11.2000          7.5319         1.2700         14.5000
 27.4600       11.4400          7.5119         1.0700         15.0000
 27.6200       11.4400          7.4934         1.0300         15.5000
 27.7000       11.5900          7.4825          .8200         16.0000
 27.8400       11.7000          7.4645          .6600         16.5000
 28.0100       11.6200          7.4425          .4900         17.0000
 28.0800       11.5800          7.4335          .5000         17.5000
 28.1600       11.5200          7.4232          .3400         18.0000
 28.1700       11.4600          7.4220          .2200         18.5000
 28.1000       11.3300          7.4309          .1700         19.0000
 28.0400       11.1000          7.4386          .1100         19.5000
 27.9900       10.8200          7.4451          .0400         20.0000
 27.8700       10.4700          7.4606          .0200         20.5000
 27.7400       10.2400          7.4776          .0100         21.0000
 27.6400        9.9000          7.4908          .0100         21.5000
 27.5500        9.5600          7.5026          .0100         22.0000
 27.4300        9.2100          7.5186          .0100         22.5000
 27.3600        8.9300          7.5279         0.0000         23.0000
 27.2700        8.6800          7.5400         0.0000         23.5000
 27.1200        8.3000          7.5602         0.0000         24.0000

     °C             mg/l            mg/l      langleys/hour
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 TEMPERATURE  OXYGEN         SATURATION    RADIATION      TIME
 27.1200        8.3000         7.5602        0.0000       0.0000
 26.9600        7.9700         7.5819       -0.0000        .5000
 26.8500        7.8300         7.5970       -0.0000       1.0000
 26.7300        7.5700         7.6135       -0.0000       1.5000
 27.4300        7.2500         7.5186       -0.0000       2.0000
 27.2200        7.2600         7.5467       -0.0000       2.5000
 26.6300        7.6300         7.6276       -0.0000       3.0000
 26.6600        7.9100         7.6231       -0.0000       3.5000
 26.7500        8.1400         7.6107       -0.0000       4.0000
 26.8000        8.3500         7.6038       -0.0000       4.5000
 26.8000        8.4700         7.6038       -0.0000       5.0000
 26.8200        8.4300         7.6011       -0.0000       5.5000
 26.7000        8.3700         7.6176       -0.0000       6.0000
 26.6200        8.2500         7.6286       -0.0000       6.5000
 26.4900        8.1300         7.6467         .0200       7.0000
 26.4100        8.0300         7.6578         .0400       7.5000
 26.3100        7.9600         7.6718         .1200       8.0000
 26.2500        7.9600         7.6803         .1900       8.5000
 26.2300        8.0300         7.6831         .2900       9.0000
 26.3100        8.2300         7.6718         .5000       9.5000
 26.4000        8.4300         7.6592         .6900      10.0000
 26.5100        8.7200         7.6435         .8400      10.5000
 26.6600        9.0500         7.6231         .9700      11.0000
 26.8600        9.4500         7.5956        1.1000      11.5000
 27.0600        9.8000         7.5686        1.1700      12.0000
 27.2300       10.1200         7.5454        1.2500      12.5000
 27.3900       10.4100         7.5239        1.2800      13.0000
 27.6200       10.6900         7.4934        1.2300      13.5000
 27.7800       11.0200         7.4724        1.3200      14.0000
 27.9300       11.2200         7.4464        1.1100      14.5000
 28.1000       11.3100         7.4309         .5800      15.0000
 28.2600       11.4400         7.4105         .6700      15.5000
 28.4700       11.4100         7.3840         .8000      16.0000
 28.5700       11.3800         7.3715         .7300      16.5000
 28.7800       11.3500         7.3455         .6700      17.0000
 28.8300       11.3100         7.3394         .5200      17.5000
 28.8400       11.2200         7.3382         .4000      18.0000
 28.8100       11.2500         7.3419         .2800      18.5000
 28.8100       11.2200         7.3419         .1600      19.0000
 28.7800       10.8500         7.3455         .0800      19.5000
 28.7300       10.5400         7.3517         .0300      20.0000
 28.5800       10.2300         7.3703         .0200      20.5000
 28.4700        9.9100         7.3840         .0100      21.0000
 28.3200        9.5800         7.4029         .0100      21.5000
 28.1400        9.2100         7.4258        0.0000      22.0000
 27.9900        8.8400         7.4451        0.0000      22.5000
 27.8400        8.5200         7.4645       -0.0000      23.0000
 27.7100        8.2400         7.4815       -0.0000      23.5000
 27.5800        7.9500         7.4987        0.0000      24.0000
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°C   mg/l   mg/l   langleys/hour

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*****************************************************
 JAMES RIVER     JUP    25 AUGUST 1974

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 TEMPERATURE   OXYGEN         SATURATION    RADIATION      TIME
 27.5800        7.9500         7.4587        0.0000        0.0000
 27.4800        7.6400         7.5119       -0.0000         .5000
 27.3500        7.4000         7.5292       -0.0000        1.0000
 27.2500        7.2100         7.5427       -0.0000        1.5000
 27.1400        7.0900         7.5575       -0.0000        2.0000
 27.0300        6.9800         7.5724       -0.0000        2.5000
 26.9500        6.8700         7.5833        0.0000        3.0000
 26.8900        6.7500         7.5915        0.0000        3.5000
 26.7900        6.6500         7.6052        0.0000        4.0000
 26.6900        6.5800         7.6190        0.0000        4.5000
 26.6200        6.5100         7.6256       -0.0000        5.0000
 26.5200        6.4300         7.6425       -0.0000        5.5000
 26.4100        6.3500         7.6575        0.0000        6.0000
 26.3700        6.3200         7.6634        0.0000        6.5000
 26.2600        6.3500         7.6789         .0200        7.0000
 26.2200        6.4200         7.6845         .0600        7.5000
 26.2000        6.5200         7.6873         .1200        8.0000
 26.2000        6.7200         7.6873         .2300        8.5000
 26.2900        7.0500         7.6747         .3600        9.0000
 26.3700        7.4600         7.6634         .5200        9.5000
 26.5100        7.8600         7.6439         .6700       10.0000
 26.6800        8.2900         7.6203         .8100       10.5000
 26.8000        8.7500         7.6038         .9200       11.0000
 27.0300        9.1600         7.5724        1.0300       11.5000
 27.2200        9.6000         7.5467        1.1100       12.0000
 27.4600        9.9300         7.5146        1.1900       12.5000
 27.5100       10.2400         7.5079        1.0500       13.0000
 27.6200       10.4800         7.4934        1.1200       13.5000
 27.8000       10.6700         7.4698        1.0800       14.0000
 27.9200       10.8000         7.4542        1.2200       14.5000
 28.0500       10.9000         7.4374        1.1200       15.0000
 28.1800       11.0300         7.4207        1.0400       15.5000
 28.2900       11.2300         7.4067         .9000       16.0000
 28.2800       11.0700         7.4080         .4800       16.5000
 28.2800       10.9300         7.4080         .3700       17.0000
 28.2800       10.9200         7.4080         .4400       17.5000
 28.2900       10.6600         7.4067         .3500       18.0000
 28.2600       10.5200         7.4105         .2000       18.5000
 28.2900       10.3600         7.4067         .1100       19.0000
 28.2900       10.2100         7.4067         .0500       19.5000
 28.2300        9.8500         7.4143         .0400       20.0000
 28.1000        9.3900         7.4309         .0700       20.5000
 28.0500        9.0600         7.4374         .0200       21.0000
 27.9200        8.8000         7.4542         .0100       21.5000
 27.8300        8.4500         7.4659         .0100       22.0000
 27.6500        8.2100         7.4894         .0100       22.5000
 27.5200        7.9100         7.5065         .0100       23.0000
 27.4200        7.6100         7.5199         .0100       23.5000
 27.3200        7.3800         7.5332        0.0000       24.0000

    °C            mg/1           mg/1      langleys/hour
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*************************************************************
  JAMES RIVER     JUP    26 AUGUST 1974

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  TEMPERATURE   OXYGEN         SATURATION    RADIATION     TIME
  27.3200       7.3300         7.5336        0.0000        0.0000
  27.1800       7.1300         7.5521        0.0000         .5000
  27.0600       7.0400         7.5683        0.0000        1.0000
  26.9200       6.9400         7.5874        0.0000        1.5000
  26.8600       6.8300         7.5956        0.0000        2.0000
  26.7900       6.7600         7.6052        0.0000        2.5000
  26.7100       6.7000         7.6162        0.0000        3.0000
  26.6200       6.6500         7.6286       -0.0000        3.5000
  26.5500       6.5800         7.6383       -0.0000        4.0000
  26.4800       6.5100         7.6481       -0.0000        4.5000
  26.4300       6.4700         7.6551        0.0000        5.0000
  26.4000       6.4400         7.6592        0.0000        5.5000
  26.3400       6.5000         7.6676        0.0000        6.0000
  26.4000       6.5400         7.6592        0.0000        6.5000
  26.3800       6.6300         7.6620         .0200        7.0000
  26.4400       6.7100         7.6537         .0400        7.5000
  26.5400       6.8200         7.6397         .0800        8.0000
  26.6500       6.9600         7.6245         .1400        8.5000
  26.7600       7.1300         7.6093         .3600        9.0000
  26.8900       7.3200         7.5915         .4600        9.5000
  26.9700       7.5500         7.5806         .5700       10.0000
  27.0400       7.7400         7.5710         .6400       10.5000
  27.0600       7.8400         7.5683         .6800       11.0000
  27.2000       8.1200         7.5494         .9100       11.5000
  27.3400       8.4100         7.5306         .9600       12.0000
  27.4600       8.6900         7.5146        1.1700       12.5000
  27.5500       8.8600         7.5026        1.2000       13.0000
  27.6700       9.0900         7.4868        1.1800       13.5000
  27.8900       9.3200         7.4580        1.2300       14.0000
  28.0100       9.5000         7.4425        1.1600       14.5000
  28.0800       9.7100         7.4335         .8900       15.0000
  28.3200       9.9000         7.4029         .7400       15.5000
  28.4300      10.1200         7.3890        1.0500       16.0000
  28.5000       9.9900         7.3802         .4600       16.5000
  28.5500       9.9600         7.3740         .5700       17.0000
  28.5200       9.9300         7.3777         .3600       17.5000
  28.5300       9.8000         7.3765         .1200       18.0000
  28.5200       9.6600         7.3777         .0600       18.5000
  28.4900       9.4900         7.3815         .0700       19.0000
  28.4300       9.2600         7.3890         .0500       19.5000
  28.2800       8.9100         7.4080         .0300       20.0000
  28.2200       8.6900         7.4156         .0200       20.5000
  28.0600       8.5400         7.4361         .0100       21.0000
  27.8900       8.0700         7.4580         .0100       21.5000
  27.6700       7.7400         7.4868        0.0000       22.0000
  27.5900       7.6400         7.4973        0.0000       22.5000
  27.5500       7.3300         7.5026        0.0000       23.0000
  27.4000       7.1450         7.5228        0.0000       23.5000
  27.3600       7.1100         7.5279        0.0000       24.0000

     °C            mg/l           mg/l       langleys/hour
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***************************************************************
 JAMES RIVER     JUP    27 AUGUST 1974

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 TEMPERATURE   OXYGEN         SATURATION   RADIATION      TIME
  27.3600       7.1100          7.5279       0.0000        0.0000
  27.4900       7.2400          7.5226       0.0000         .5000
  27.4800       7.4300          7.5119      -0.0000        1.0000
  27.5500       7.6500          7.5026      -0.0000        1.5000
  27.5500       7.7400          7.5026      -0.0000        2.0000
  27.4300       7.7400          7.5186      -0.0000        2.5000
  27.3200       7.6600          7.5333      -0.0000        3.0000
  27.1700       7.5500          7.5534       0.0000        3.5000
  27.0700       7.4600          7.5670       0.0000        4.0000
  26.9500       7.4000          7.5833      -0.0000        4.5000
  26.8500       7.4100          7.5970      -0.0000        5.0000
  26.7800       7.3900          7.6066      -0.0000        5.5000
  26.7600       7.3700          7.6093      -0.0000        6.0000
  26.7200       7.3300          7.6148      -0.0000        6.5000
  26.7300       7.3300          7.6135        .0100        7.0000
  26.6800       7.3200          7.6203        .0400        7.5000
  26.6600       7.2900          7.6231        .0800        8.0000
  26.6300       7.2400          7.6273        .1300        8.5000
  26.6100       7.2500          7.6300        .1800        9.0000
  26.6100       7.2000          7.6300        .2500        9.5000
  26.5900       7.2000          7.6326        .2700       10.0000
  26.6100       7.2100          7.6300        .3100       10.5000
  26.6300       7.3300          7.6273        .5400       11.0000
  26.7500       7.4600          7.6107        .7800       11.5000
  26.8900       7.7100          7.5915       1.1700       12.0000
  27.0300       7.9100          7.5724       1.2400       12.5000
  27.2000       8.0100          7.5494       1.2800       13.0000
  27.2700       8.0700          7.5400       1.2900       13.5000
  27.4200       8.1100          7.5199       1.2300       14.0000
  27.5400       8.2100          7.5040       1.1900       14.5000
  27.7400       8.3700          7.4776       1.1100       15.0000
  27.8900       8.4800          7.4580        .9800       15.5000
  28.0400       8.5500          7.4386        .9400       16.0000
  28.1600       8.6500          7.4232        .8200       16.5000
  28.2300       8.7300          7.4143        .6900       17.0000
  28.3100       8.7600          7.4042        .5600       17.5000
  28.3100       8.7600          7.4042        .4000       18.0000
  28.2600       8.7300          7.4096        .2000       18.5000
  28.2300       8.7000          7.4143        .1200       19.0000
  28.2300       8.5900          7.4143        .0700       19.5000
  28.1100       8.5300          7.4296        .0300       20.0000
  28.0400       8.3800          7.4386        .0200       20.5000
  27.9500       8.3900          7.4503        .0100       21.0000
  27.7800       8.1800          7.4724        .0100       21.5000
  27.5400       8.0200          7.5040        .0100       22.0000
  27.3600       7.9200          7.5279        .0100       22.5000
  27.2000       7.9000          7.5494        .0100       23.0000
  27.0600       7.7400          7.5683       0.0000       23.5000
  26.9700       7.7800          7.5808       0.0000       24.0000

     °C           mg/l            mg/l      langleys/hour
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JAMES RIVER    JUP      28 AUGUST 1974

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 TEMPERATURE   OXYGEN          SATURATION    RADIATION      TIME
  26.9700       7.7000          7.5506        0.0000        0.0000
  26.9600       7.8600          7.5819       -0.0000         .5000
  27.0200       8.0900          7.5736        0.0000        1.0000
  27.0700       8.1900          7.5670        0.0000        1.5000
  27.0400       8.1900          7.5710        0.0000        2.0000
  26.9900       8.0600          7.5778        0.0000        2.5000
  26.9300       7.8700          7.5860        0.0000        3.0000
  26.8200       7.6600          7.6011        0.0000        3.5000
  26.6600       7.4200          7.6231        0.0000        4.0000
  26.5800       7.2500          7.6342        0.0000        4.5000
  26.5100       7.1000          7.6439        0.0000        5.0000
  26.4400       6.9600          7.6537        0.0000        5.5000
  26.3600       6.8700          7.6646        0.0000        6.0000
  26.3000       6.7600          7.6733        0.0000        6.5000
  26.2700       6.6800          7.6775         .0200        7.0000
  26.2500       6.5900          7.6803         .0400        7.5000
  26.2200       6.5900          7.6845         .1000        8.0000
  26.2200       6.5400          7.6845         .1400        8.5000
  26.2200       6.5500          7.6845         .2200        9.0000
  26.2600       6.5700          7.6789         .2800        9.5000
  26.2700       6.6100          7.6775         .2600       10.0000
  26.3700       6.6800          7.6634         .4500       10.5000
  26.4900       6.8500          7.6467         .7700       11.0000
  26.5900       7.0200          7.6328         .6500       11.5000
  26.6800       7.1800          7.6203         .6300       12.0000
  26.8000       7.3500          7.6038         .6600       12.5000
  26.9000       7.5500          7.5901         .7300       13.0000
  27.0600       7.7200          7.5683         .9700       13.5000
  27.2400       7.9200          7.5446        1.0500       14.0000
  27.3300       8.1800          7.5319         .9400       14.5000
  27.5400       8.4600          7.5040        1.0500       15.0000
  27.7400       8.5600          7.4776        1.0700       15.5000
  27.8900       8.8500          7.4580         .8200       16.0000
  28.0300       9.0400          7.4399         .7100       16.5000
  28.2300       9.2400          7.4143         .7100       17.0000
  28.3500       9.3600          7.3991         .5500       17.5000
  28.4100       9.4700          7.3915         .3800       18.0000
  28.4900       9.3800          7.3815         .2200       18.5000
  28.4600       9.3700          7.3853         .0800       19.0000
  28.4700       9.1800          7.3846         .0500       19.5000
  28.4300       9.0300          7.3890         .0400       20.0000
  28.3700       8.7100          7.3966         .0200       20.5000
  28.2200       8.6000          7.4156         .0200       21.0000
  28.1700       8.3800          7.4226         .0200       21.5000
  28.0500       8.1700          7.4374         .0100       22.0000
  27.9200       8.0500          7.4542         .0100       22.5000
  27.7600       7.9700          7.4750         .0100       23.0000
  27.5900       7.9300          7.4973         .0100       23.5000
  27.4600       7.9800          7.5146        0.0000       24.0000

   °C            mg/1            mg/1       langleys/hour
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****************************************************
JAMES RIVER    JUP       29 AUGUST 1974

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TEMPERATURE   OXYGEN      SATURATION    RADIATION      TIME
 27.4600       7.9800      7.5146        0.0000        0.0000
 27.2500       7.7300      7.5427       -0.0000         .5000
 27.0600       7.6900      7.5683       -0.0000        1.0000
 27.0100       7.8700      7.5751        -.0100        1.5000
 27.0700       8.1700      7.5670        -.0100        2.0000
 27.0600       8.3300      7.5683        -.0100        2.5000
 27.0400       8.4200      7.5710        -.0100        3.0000
 26.9600       8.2900      7.5819        -.0100        3.5000
 26.8500       8.1400      7.5970        -.0100        4.0000
 26.7200       7.9700      7.6148        -.0100        4.5000
 26.6500       7.8700      7.6245        -.0100        5.0000
 26.5800       7.7600      7.6342        -.0100        5.5000
 26.5200       7.7200      7.6425        -.0100        6.0000
 26.4900       7.5900      7.6467       -0.0000        6.5000
 26.4300       7.5700      7.6551         .0700        7.0000
 26.4400       7.4900      7.6537         .0200        7.5000
 26.4100       7.4500      7.6578         .1300        8.0000
 26.4500       7.4700      7.6523         .3200        8.5000
 26.5200       7.5100      7.6425         .5100        9.0000
 26.6800       7.6200      7.6203         .7200        9.5000
 26.8300       7.7900      7.5997         .8600       10.0000
 26.8600       7.9500      7.5929         .7200       10.5000
 27.0400       8.1300      7.5710         .8000       11.0000
 27.2300       8.3700      7.5454        1.0700       11.5000
 27.4200       8.5900      7.5199        1.2000       12.0000
 27.6400       8.8800      7.4908        1.2600       12.5000
 27.8100       9.1800      7.4675        1.3700       13.0000
 27.9800       9.3700      7.4464        1.1300       13.5000
 28.1700       9.3600      7.4220        1.2200       14.0000
 28.2800       9.5300      7.4080         .7800       14.5000
 28.4300       9.6400      7.3890         .9500       15.0000
 28.4700       9.6600      7.3840         .6700       15.5000
 28.4400       9.8200      7.3878         .1600       16.0000
 28.6300       9.9800      7.3640         .2900       16.5000
 28.6900       9.9200      7.3566         .0900       17.0000
 28.5700       9.6100      7.3715         .0300       17.5000
 28.5000       9.4500      7.3802         .1100       18.0000
 28.5300       9.2500      7.3765         .3000       18.5000
 28.4300       9.0100      7.3890         .2000       19.0000
 28.2800       8.7900      7.4080         .0700       19.5000
 28.1700       8.5300      7.4220         .0200       20.0000
 28.0400       8.2600      7.4386         .0100       20.5000
 27.9300       8.0000      7.4525         .0100       21.0000
 27.7800       7.7100      7.4724        0.0000       21.5000
 27.7100       7.5400      7.4815        0.0000       22.0000
 27.6400       7.5700      7.4908        0.0000       22.5000
 27.6400       7.5200      7.4908        0.0000       23.0000
 27.5900       7.4200      7.4973        0.0000       23.5000
 27.5100       7.2800      7.5079        0.0000       24.0000

     °C          mg/l         mg/l       langleys/hour
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JAMES RIVER    JUP      30 AUGUST 1974

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TEMPERATURE   OXYGEN        SATURATION   RADIATION      TIME
  27.5100      7.2800        7.5079       0.0000        0.0000
  27.4500      7.1400        7.5159      -0.0000         .5000
  27.3300      6.9700        7.5319      -0.0000        1.0000
  27.2300      6.8800        7.5454      -0.0000        1.5000
  27.0900      6.7800        7.5643      -0.0000        2.0000
  26.9600      6.7200        7.5819      -0.0000        2.5000
  26.8300      6.6700        7.5997      -0.0000        3.0000
  26.7200      6.6800        7.6148      -0.0000        3.5000
  26.5900      6.7800        7.6326      -0.0000        4.0000
  26.5200      6.8700        7.6425      -0.0000        4.5000
  26.5200      6.9400        7.6425      -0.0000        5.0000
  26.6100      7.0600        7.6300      -0.0000        5.5000
  26.6500      7.2500        7.6245      -0.0000        6.0000
  26.7000      7.4000        7.6176      -0.0000        6.5000
  26.7400      7.5000        7.6121        .0300        7.0000
  26.7500      7.5600        7.6107        .1200        7.5000
  26.7000      7.5600        7.6176        .1700        8.0000
  26.6800      7.4800        7.6203        .1800        8.5000
  26.6200      7.4600        7.6286        .3000        9.0000
  26.6000      7.4500        7.6314        .3700        9.5000
  26.6900      7.6200        7.6190        .8100       10.0000
  26.6800      7.6600        7.6203        .5100       10.5000
  26.7000      7.8200        7.6176        .4000       11.0000
  26.7500      7.9900        7.6107        .4500       11.5000
  26.8300      8.0800        7.5997        .5000       12.0000
  27.0300      8.3500        7.5724       1.0000       12.5000
  27.2200      8.5400        7.5467       1.2100       13.0000
  27.3300      8.8500        7.5319       1.1900       13.5000
  27.5800      9.0800        7.4987       1.1600       14.0000
  27.7600      9.2700        7.4750        .9800       14.5000
  27.8400      9.4800        7.4645       1.0200       15.0000
  27.9800      9.5500        7.4464       1.0300       15.5000
  28.0400      9.6800        7.4386        .6800       16.0000
  28.1700      9.7800        7.4220        .4500       16.5000
  28.2600      9.9200        7.4105        .3800       17.0000
  28.3400      9.8600        7.4004        .2600       17.5000
  28.3400      9.6800        7.4004        .1900       18.0000
  28.2600      9.5000        7.4105        .1700       18.5000
  28.2300      9.3100        7.4143        .0900       19.0000
  28.1400      9.1300        7.4258        .0500       19.5000
  28.0200      8.8300        7.4412        .0300       20.0000
  27.9000      8.5500        7.4567        .0300       20.5000
  27.8100      8.3100        7.4685        .0700       21.0000
  27.7400      8.0800        7.4776        .0200       21.5000
  27.6100      7.9200        7.4947        .0200       22.0000
  27.5800      7.7300        7.4987        .0100       22.5000
  27.5400      7.5800        7.5040        .0100       23.0000
  27.4600      7.3900        7.5146        .0100       23.5000
  27.3600      7.2300        7.5279       0.0000       24.0000

    °C          mg/1          mg/1      langleys/hour
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************************************************
JAMES RIVER   JOP      31 AUGUST 1974

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TEMPERATURE   OXYGEN         SATURATION   RADIATION      TIME
 27.3600       7.2300         7.5279        0.0000       0.0000
 27.2900       7.1000         7.5372       -0.0000        .5000
 27.2000       6.9800         7.5494       -0.0000       1.0000
 27.1000       6.8400         7.5625       -0.0000       1.5000
 27.0700       6.7400         7.5670       -0.0000       2.0000
 27.0300       6.7800         7.5724       -0.0000       2.5000
 27.0200       6.8600         7.5738       -0.0000       3.0000
 26.9800       6.9500         7.5792       -0.0000       3.5000
 27.0000       7.0200         7.5765       -0.0000       4.0000
 26.9500       7.1100         7.5833       -0.0000       4.5000
 26.8900       7.1300         7.5915       -0.0000       5.0000
 26.7900       7.1300         7.6052       -0.0000       5.5000
 26.7000       7.1000         7.6176       -0.0000       6.0000
 26.5900       7.0500         7.6328       -0.0000       6.5000
 26.5200       7.0100         7.6425         .0100       7.0000
 26.4400       7.0100         7.6537         .0800       7.5000
 26.4000       6.9700         7.6592         .1300       8.0000
 26.4000       6.9800         7.6592         .2300       8.5000
 26.3300       7.0900         7.6690         .2600       9.0000
 26.4700       7.2900         7.6495         .5700       9.5000
 26.4800       7.4400         7.6481         .5000      10.0000
 26.5600       7.5500         7.6370         .6000      10.5000
 26.7000       7.8600         7.6176         .7500      11.0000
 26.7800       8.0300         7.6066         .7300      11.5000
 26.8300       8.2600         7.5997         .6500      12.0000
 26.8600       8.4600         7.5956         .5100      12.5000
 26.9500       8.5900         7.5833         .4700      13.0000
 27.0400       8.8200         7.5710         .4600      13.5000
 27.0300       8.9400         7.5724         .3700      14.0000
 27.1700       9.0800         7.5534         .6900      14.5000
 27.2000       9.3000         7.5494         .5600      15.0000
 27.3000       9.3300         7.5359         .7600      15.5000
 27.3900       9.4800         7.5239        1.1300      16.0000
 27.3800       9.4800         7.5252         .7300      16.5000
 27.3900       9.4400         7.5239         .4200      17.0000
 27.3900       9.4000         7.5239         .1500      17.5000
 27.3900       9.4300         7.5239         .3100      18.0000
 27.3600       9.3500         7.5279         .2100      18.5000
 27.2900       9.2100         7.5372         .0900      19.0000
 27.3000       9.1900         7.5359         .0400      19.5000
 27.2900       9.0100         7.5372         .0200      20.0000
 27.1900       8.6100         7.5507         .0100      20.5000
 27.0400       8.3200         7.5710         .0100      21.0000
 26.8900       8.0600         7.5915         .0300      21.5000
 26.7600       7.8400         7.6093         .0400      22.0000
 26.6500       7.6600         7.6245       -0.0000      22.5000
 26.5400       7.5900         7.6397        -.0100      23.0000
 26.4700       7.3500         7.6495        -.0100      23.5000
 26.3700       7.2000         7.6634        0.0000      24.0000

   °C          mg/1           mg/1       langleys/hour
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*****************************************************************
 JAMES RIVER      JUF     1 SEPTEMBER 1974

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 TEMPERATURE   OXYGEN        SATURATION    RADIATION      TIME
  26.3700       7.2000        7.6634        0.0000       0.0000
  26.2700       7.1000        7.6775        0.0000        .5000
  26.1900       7.0300        7.6887        0.0000       1.0000
  26.1400       7.0000        7.6956        0.0000       1.5000
  26.1100       7.0000        7.7000        0.0000       2.0000
  26.1000       7.0400        7.7014        0.0000       2.5000
  26.0900       7.1000        7.7028       -0.0000       3.0000
  26.0800       7.1700        7.7042       -0.0000       3.5000
  26.0800       7.2200        7.7042       -0.0000       4.0000
  26.0500       7.2600        7.7085       -0.0000       4.5000
  26.0100       7.2900        7.7142       -0.0000       5.0000
  25.9300       7.3100        7.7256       -0.0000       5.5000
  25.9200       7.2600        7.7270       -0.0000       6.0000
  25.8100       7.2700        7.7427        0.0000       6.5000
  25.7500       7.2400        7.7513         .0400       7.0000
  25.6900       7.2400        7.7599         .0900       7.5000
  25.6600       7.2400        7.7642         .1400       8.0000
  25.6500       7.2400        7.7656         .2200       8.5000
  25.7000       7.3900        7.7585         .5000       9.0000
  25.7700       7.5300        7.7484         .6700       9.5000
  25.8500       7.6700        7.7370         .6900      10.0000
  25.9800       7.8600        7.7184         .9700      10.5000
  26.0000       7.9300        7.7156         .6300      11.0000
  26.1200       8.1000        7.6986         .7300      11.5000
  26.3400       8.3000        7.6676         .9800      12.0000
  26.4400       8.4000        7.6537         .8100      12.5000
  26.6200       8.6100        7.6286        1.1100      13.0000
  26.6800       8.6500        7.6202         .7100      13.5000
  26.7800       8.6800        7.6066         .8400      14.0000
  26.8200       8.7200        7.6011         .8600      14.5000
  26.9500       8.7800        7.5833        1.0900      15.0000
  27.0200       8.8300        7.5738         .6900      15.5000
  27.0600       8.9100        7.5683         .2400      16.0000
  27.1200       8.9200        7.5602         .4400      16.5000
  27.1200       8.7900        7.5602         .2300      17.0000
  27.0300       8.7500        7.5724         .1200      17.5000
  27.0200       8.6300        7.5738         .1200      18.0000
  26.9500       8.5200        7.5833         .0700      18.5000
  26.8600       8.3600        7.5956         .2500      19.0000
  26.7900       8.1400        7.6052         .0800      19.5000
  26.6300       8.0100        7.6273         .0200      20.0000
  26.5100       7.9000        7.6439         .0200      20.5000
  26.4100       7.7500        7.6578         .0300      21.0000
  26.3100       7.5800        7.6716         .0200      21.5000
  26.1500       7.5000        7.6944         .0200      22.0000
  26.0800       7.4600        7.7043         .0100      22.5000
  26.0300       7.3600        7.7112         .0100      23.0000
  25.9600       7.3000        7.7213         .0100      23.5000
  25.8900       7.1800        7.7313        0.0000      24.0000

     °C           mg/l          mg/l     langleys/hour
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JAMES RIVER JUP 2 SEPTEMBER 1974

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TEMPERATURE	OXYGEN	SATURATION	RADIATION	TIME
25.8900	7.1800	7.7313	0.0000	0.0000
25.8100	7.0800	7.7427	-0.0000	.5000
25.7100	7.0200	7.7570	-0.0000	1.0000
25.6100	6.9400	7.7714	-0.0000	1.5000
25.5700	6.8800	7.7772	-0.0000	2.0000
25.4900	6.8100	7.7887	-0.0000	2.5000
25.4200	6.7900	7.7989	0.0000	3.0000
25.3700	6.7400	7.8061	0.0000	3.5000
25.2700	6.7500	7.8207	-0.0000	4.0000
25.2500	6.7900	7.8236	-0.0000	4.5000
25.2200	6.7900	7.8280	-0.0000	5.0000
25.2000	6.8100	7.8309	-0.0000	5.5000
25.1700	6.8600	7.8353	-0.0000	6.0000
25.1800	6.8800	7.8338	-0.0000	6.5000
25.1800	6.9400	7.8338	.0100	7.0000
25.2000	6.9800	7.8309	.0500	7.5000
25.2200	7.0200	7.8280	.1000	8.0000
25.2300	7.1200	7.8265	.1800	8.5000
25.3000	7.2300	7.8163	.2400	9.0000
25.4200	7.3800	7.7989	.5300	9.5000
25.4300	7.5400	7.7974	.7600	10.0000
25.5800	7.7000	7.7757	.7400	10.5000
25.6100	7.7800	7.7714	.5400	11.0000
25.7300	7.9300	7.7542	.6900	11.5000
25.8400	8.1000	7.7384	.8200	12.0000
25.8500	8.2900	7.7370	.6700	12.5000
25.9600	8.4300	7.7184	.4500	13.0000
25.9800	8.4200	7.7184	.3000	13.5000
26.0500	8.4700	7.7085	.5500	14.0000
26.0700	8.5400	7.7057	.5800	14.5000
26.0800	8.5400	7.7043	.6300	15.0000
26.0900	8.5800	7.7028	.4200	15.5000
26.1200	8.5200	7.6986	.3800	16.0000
26.1500	8.5800	7.6944	.4400	16.5000
26.2200	8.5200	7.6845	.1600	17.0000
26.2000	8.5300	7.6873	.1700	17.5000
26.2000	8.3900	7.6873	.1300	18.0000
26.1600	8.2600	7.6930	.0700	18.5000
26.0400	8.1700	7.7099	.0300	19.0000
25.9400	7.9800	7.7241	.0200	19.5000
25.8400	7.7900	7.7384	.0200	20.0000
25.6700	7.7500	7.7628	.0100	20.5000
25.6600	7.6300	7.7642	.0200	21.0000
25.5500	7.6000	7.7801	.0100	21.5000
25.5100	7.5600	7.7858	.0100	22.0000
25.5000	7.5100	7.7873	.0100	22.5000
25.4900	7.4200	7.7887	.0100	23.0000
25.5000	7.3700	7.7873	.0100	23.5000
25.5100	7.3500	7.7858	0.0000	24.0000
ºC	mg/1	mg/1	langleys/hour	

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*************************************************************
 JAMES RIVER      JUP      6 SEPTEMBER 1974

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 TEMPERATURE   OXYGEN          SATURATION     RADIATION       TIME
  19.9000        8.4100          8.6665         0.0000        0.0000
  19.8900        8.4100          8.6682        -0.0000         .5000
  19.9000        8.4000          8.6665        -0.0000        1.0000
  19.8800        8.4100          8.6699        -0.0000        1.5000
  19.9000        8.3800          8.6665         0.0000        2.0000
  19.9100        8.3900          8.6648        -0.0000        2.5000
  19.9000        8.3900          8.6665        -0.0000        3.0000
  19.8800        8.3600          8.6699        -0.0000        3.5000
  19.8700        8.3600          8.6716        -0.0000        4.0000
  19.8600        8.3800          8.6733        -0.0000        4.5000
  19.8600        8.3600          8.6733        -0.0000        5.0000
  19.8500        8.3500          8.6749        -0.0000        5.5000
  19.8500        8.3400          8.6749        -0.0000        6.0000
  19.8100        8.3300          8.6817        -0.0000        6.5000
  19.8100        8.3200          8.6817         0.0000        7.0000
  19.7700        8.3200          8.6885          .0100        7.5000
  19.7800        8.3300          8.6868          .0200        8.0000
  19.7500        8.3200          8.6919          .0700        8.5000
  19.7300        8.3200          8.6952          .1100        9.0000
  19.7300        8.3400          8.6952          .1600        9.5000
  19.7300        8.3300          8.6952          .1800       10.0000
  19.7500        8.3500          8.6919          .4000       10.5000
  19.7600        8.3700          8.6902          .4200       11.0000
  19.8300        8.3400          8.6783          .2800       11.5000
  19.8300        8.3600          8.6783          .3000       12.0000
  19.8700        8.3800          8.6716          .3100       12.5000
  19.8800        8.3800          8.6699          .5000       13.0000
  19.9700        8.3900          8.6547         1.0400       13.5000
  20.0900        8.4000          8.6362          .9100       14.0000
  20.1500        8.4000          8.6245          .9900       14.5000
  20.2800        8.4000          8.6027         1.0600       15.0000
  20.4000        8.3900          8.5827         1.2500       15.5000
  20.4200        8.3900          8.5794         1.0900       16.0000
  20.5500        8.3100          8.5578          .7000       16.5000
  20.6600        8.2900          8.5395          .4700       17.0000
  20.6600        8.3100          8.5395          .3200       17.5000
  20.6400        8.3300          8.5425          .2000       18.0000
  20.6100        8.3200          8.5476          .2300       18.5000
  20.5700        8.3300          8.5545          .1200       19.0000
  20.5300        8.3700          8.5611          .0500       19.5000
  20.5300        8.3800          8.5611          .0200       20.0000
  20.4600        8.3300          8.5727          .0200       20.5000
  20.4200        8.3700          8.5794          .0200       21.0000
  20.4200        8.3600          8.5794          .0700       21.5000
  20.4200        8.3500          8.5794          .0100       22.0000
  20.4200        8.3500          8.5794          .0100       22.5000
  20.4300        8.3300          8.5777         0.0000       23.0000
  20.4500        8.3200          8.5744         0.0000       23.5000
  20.4300        8.3200          8.5777         0.0000       24.0000

     °C             mg/1            mg/1       langleys/hour
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JAMES RIVER       JUR      9 SEPTEMBER 1974

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TEMPERATURE  OXYGEN        SATURATION   RADIATION     TIME
 20.4300       8.3200        8.5777       0.0000       0.0000
 20.4000       8.3200        8.5827      -0.0000        .5000
 20.3600       8.3200        8.5860      -0.0000       1.0000
 20.3300       8.3200        8.5944      -0.0000       1.5000
 20.3600       8.2900        8.5894      -0.0000       2.0000
 20.3100       8.3000        8.5977      -0.0000       2.5000
 20.3100       8.2900        8.5977      -0.0000       3.0000
 20.3100       8.2800        8.5977      -0.0000       3.5000
 20.3500       8.2600        8.5910      -0.0000       4.0000
 20.3700       8.2300        8.5877      -0.0000       4.5000
 20.3600       8.2400        8.5894      -0.0000       5.0000
 20.3300       8.2200        8.5944      -0.0000       5.5000
 20.3100       8.2100        8.5977      -0.0000       6.0000
 20.3100       8.1800        8.5977      -0.0000       6.5000
 20.2800       8.1700        8.6027       0.0000       7.0000
 20.2800       8.1500        8.6027        .0400       7.5000
 20.2800       8.1300        8.6027        .0900       8.0000
 20.2700       8.1200        8.6044        .1500       8.5000
 20.2800       8.1200        8.6027        .2200       9.0000
 20.2900       8.1200        8.6010        .3300       9.5000
 20.3200       8.1100        8.5960        .4700      10.0000
 20.3500       8.1500        8.5910        .7900      10.5000
 20.4400       8.1500        8.5760        .9300      11.0000
 20.5800       8.1500        8.5528        .9400      11.5000
 20.5900       8.2100        8.5511        .6200      12.0000
 20.6700       8.2400        8.5379        .7400      12.5000
 20.8200       8.2600        8.5131        .8400      13.0000
 20.9100       8.2900        8.4983       1.0300      13.5000
 20.9800       8.2700        8.4866       1.1600      14.0000
 21.0800       8.3100        8.4704       1.1500      14.5000
 21.0500       8.3100        8.4753        .4900      15.0000
 21.0700       8.3000        8.4721        .9800      15.5000
 21.0200       8.3000        8.4803        .7300      16.0000
 21.0500       8.2800        8.4753        .8100      16.5000
 21.1000       8.3000        8.4672        .5700      17.0000
 21.1500       8.3100        8.4590        .3500      17.5000
 21.1000       8.3100        8.4672        .2500      18.0000
 21.0000       8.2800        8.4835        .1600      18.5000
 21.0100       8.2700        8.4819        .0800      19.0000
 20.9900       8.3000        8.4852        .0400      19.5000
 20.9900       8.2700        8.4852        .0300      20.0000
 20.9800       8.2600        8.4868        .0400      20.5000
 21.0000       8.2500        8.4835        .0300      21.0000
 21.0000       8.2400        8.4835        .0300      21.5000
 21.0200       8.2300        8.4803        .0200      22.0000
 21.0400       8.2100        8.4770        .0300      22.5000
 21.0400       8.2300        8.4770        .0200      23.0000
 21.0600       8.2200        8.4737        .0100      23.5000
 21.1000       8.2100        8.4672       0.0000      24.0000

   °C           mg/1          mg/1       langleys/hour
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 JAMES RIVER      JUP    10 SEPTEMBER 1974

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 TEMPERATURE   OXYGEN         SATURATION   RADIATION      TIME
  21.1000       8.2100         8.4672       0.0000       0.0000
  21.0900       8.2200         8.4688       0.0000        .5000
  21.1200       8.2100         8.4639       0.0000       1.0000
  21.1100       8.1300         8.4655       0.0000       1.5000
  21.0800       8.1600         8.4704       0.0000       2.0000
  21.0500       8.1300         8.4753       0.0000       2.5000
  21.0500       8.1800         8.4753       0.0000       3.0000
  21.0400       8.1600         8.4770       0.0000       3.5000
  21.0000       8.1700         8.4835       0.0000       4.0000
  21.0000       8.1500         8.4835       0.0000       4.5000
  21.0000       8.1200         8.4835       0.0000       5.0000
  20.9800       8.1000         8.4868       0.0000       5.5000
  20.9400       8.1000         8.4934       0.0000       6.0000
  20.9800       8.0800         8.4868      -0.0000       6.5000
  20.9600       8.0500         8.4901       0.0000       7.0000
  20.9100       8.0100         8.4983        .0200       7.5000
  20.9100       7.9300         8.4983        .0700       8.0000
  20.9100       7.9700         8.4983        .1500       8.5000
  20.8900       8.0100         8.5016        .2600       9.0000
  20.9300       8.0200         8.4950        .3600       9.5000
  21.0400       8.0700         8.4770        .6700      10.0000
  21.1600       8.1100         8.4573        .8400      10.5000
  21.3100       8.1900         8.4329        .9500      11.0000
  21.4800       8.2200         8.4053       1.1100      11.5000
  21.6600       8.2600         8.3762       1.0700      12.0000
  21.7900       8.3400         8.3552       1.0500      12.5000
  22.0100       8.3900         8.3199       1.0800      13.0000
  22.0900       8.4000         8.3072        .9400      13.5000
  22.1200       8.4500         8.3024        .6300      14.0000
  22.1200       8.4500         8.3024        .3500      14.5000
  22.1100       8.4200         8.3040        .4500      15.0000
  22.1100       8.3800         8.3040        .5300      15.5000
  22.1700       8.3700         8.2944        .5900      16.0000
  22.0900       8.3000         8.3072        .6400      16.5000
  22.1000       8.3300         8.3056        .5600      17.0000
  22.0800       8.2900         8.3088        .5700      17.5000
  22.0900       8.2300         8.3072        .3500      18.0000
  21.9800       8.2000         8.3247        .1700      18.5000
  21.9500       8.2100         8.3295        .0700      19.0000
  21.9400       8.2100         8.3311        .0400      19.5000
  21.8800       8.1600         8.3408        .0300      20.0000
  21.8300       8.1700         8.3438        .0400      20.5000
  21.7900       8.1400         8.3552        .0300      21.0000
  21.7700       8.1200         8.3584        .0500      21.5000
  21.7000       8.1100         8.3697        .0400      22.0000
  21.7000       8.0500         8.3697        .0200      22.5000
  21.7100       8.0100         8.3681        .0100      23.0000
  21.7500       7.9500         8.3617        .0100      23.5000
  21.7500       7.9400         8.3617       0.0000      24.0000
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°C mg/1 mg/1 langleys/hour

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*******************************************************
 JAMES RIVER      JUP    11 SEPTEMBER 1974 .

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 TEMPERATURE  OXYGEN         SATURATION     RADIATION      TIME
 21.7500       7.9400         8.3617         0.0000        0.0000
 21.7900       7.9100         8.3552        -0.0000         .5000
 21.7800       7.9700         8.3568         0.0000        1.0000
 21.7800       7.9300         8.3568        -0.0000        1.5000
 21.7600       7.9600         8.3600        -0.0000        2.0000
 21.7700       7.9800         8.3584        -0.0000        2.5000
 21.7500       8.0200         8.3617        -0.0000        3.0000
 21.7100       8.0400         8.3681         -.0100        3.5000
 21.7000       8.0500         8.3697         -.0100        4.0000
 21.6600       8.0600         8.3762         -.0100        4.5000
 21.6400       8.0800         8.3794         -.0100        5.0000
 21.5800       8.0700         8.3891        -0.0000        5.5000
 21.5600       8.0700         8.3923         -.0100        6.0000
 21.5400       8.0600         8.3956         -.0100        6.5000
 21.5800       8.0100         8.3891        -0.0000        7.0000
 21.5600       7.9900         8.3923          .0200        7.5000
 21.5500       7.9500         8.3939          .0600        8.0000
 21.5500       7.9300         8.3939          .1300        8.5000
 21.5500       7.9300         8.3939          .2100        9.0000
 21.5200       7.9400         8.3988          .2800        9.5000
 21.5200       7.9700         8.3988          .4800       10.0000
 21.6400       7.9700         8.3794          .7700       10.5000
 21.7500       7.9900         8.3617          .9600       11.0000
 21.9300       8.0600         8.3327         1.0600       11.5000
 22.1100       8.1200         8.3040         1.1700       12.0000
 22.2400       8.1500         8.2833         1.0700       12.5000
 22.4300       8.1900         8.2531         1.2900       13.0000
 22.6300       8.2200         8.2218         1.3000       13.5000
 22.7500       8.2800         8.2027         1.2600       14.0000
 22.8300       8.3400         8.1901         1.2000       14.5000
 22.9500       8.3200         8.1714          .9200       15.0000
 23.0700       8.3300         8.1527         1.0500       15.5000
 23.1100       8.3500         8.1465          .8700       16.0000
 23.2700       8.3400         8.1216          .7500       16.5000
 23.2900       8.3600         8.1185          .6700       17.0000
 23.3300       8.3300         8.1123          .5200       17.5000
 23.3200       8.3200         8.1139          .3700       18.0000
 23.2700       8.3100         8.1216          .2300       18.5000
 23.1700       8.3100         8.1371          .1200       19.0000
 23.0900       8.3300         8.1496          .0500       19.5000
 22.9700       8.2700         8.1683          .0300       20.0000
 22.8700       8.2100         8.1839          .0300       20.5000
 22.7600       8.1600         8.2011          .0300       21.0000
 22.7000       8.1300         8.2105          .0200       21.5000
 22.6400       8.1200         8.2200          .0300       22.0000
 22.7400       5.1100         8.2043         -.0100       22.5000
 22.7800       8.1300         8.1980         0.0000       23.0000
 22.8100       8.1300         8.1933        -0.0000       23.5000
 22.8200       8.0800         8.1917         0.0000       24.0000

    °C           mg/1           mg/1      langleys/hour
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***********************************************************
 JAMES RIVER      JUP    12 SEPTEMBER 1974

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 TEMPERATURE   OXYGEN        SATURATION    RADIATION      TIME
  23.2300       7.7800        8.1201        0.0000        0.0000
  23.2600       7.7600        8.1201       -0.0000         .5000
  23.2600       7.7400        8.1232        0.0000        1.0000
  23.2600       7.7000        8.1232        0.0000        1.5000
  23.2600       7.6800        8.1232       -0.0000        2.0000
  23.2600       7.6700        8.1232       -0.0000        2.5000
  23.2600       7.6400        8.1232       -0.0000        3.0000
  23.2300       7.6200        8.1279       -0.0000        3.5000
  23.2000       7.5400        8.1325       -0.0000        4.0000
  23.1400       7.4600        8.1418       -0.0000        4.5000
  23.0800       7.3800        8.1511       -0.0000        5.0000
  23.0600       7.3000        8.1542        -.0100        5.5000
  23.0100       7.2300        8.1620        -.0100        6.0000
  22.9800       7.1600        8.1667        -.0100        6.5000
  22.9500       7.1100        8.1714       -0.0000        7.0000
  22.8900       7.0800        8.1808         .0200        7.5000
  22.8400       7.0700        8.1886         .0700        8.0000
  22.7900       7.0500        8.1964         .1500        8.5000
  22.8200       7.0900        8.1917         .3400        9.0000
  22.8700       7.1200        8.1839         .5300        9.5000
  22.9400       7.1400        8.1729         .6900       10.0000
  23.0300       7.1700        8.1565         .8300       10.5000
  23.1900       7.2100        8.1340         .9600       11.0000
  23.3300       7.2800        8.1123        1.0400       11.5000
  23.5300       7.3400        8.0815        1.1300       12.0000
  23.7200       7.4100        8.0524        1.1800       12.5000
  23.9100       7.4700        8.0234        1.2200       13.0000
  24.0900       7.5400        7.9961        1.2700       13.5000
  24.1900       7.6300        7.9810        1.2200       14.0000
  24.3600       7.6700        7.9554        1.1200       14.5000
  24.4700       7.7100        7.9389         .9100       15.0000
  24.5600       7.7400        7.9255        1.0400       15.5000
  24.6800       7.7900        7.9076         .8000       16.0000
  24.8200       7.8400        7.8868         .7900       16.5000
  24.8400       7.8800        7.8839         .6600       17.0000
  24.8200       7.8900        7.8868         .4400       17.5000
  24.8300       7.8700        7.8853         .1300       18.0000
  24.7500       7.8300        7.8972         .0900       18.5000
  24.6900       7.8000        7.9161         .0500       19.0000
  24.5900       7.7500        7.9210         .0300       19.5000
  24.4600       7.6600        7.9404         .0200       20.0000
  24.3600       7.5700        7.9554         .0300       20.5000
  24.2200       7.4600        7.9765         .0200       21.0000
  24.0700       7.4300        7.9991         .0200       21.5000
  23.8900       7.3800        8.0265         .0200       22.0000
  23.7100       7.3700        8.0539         .0100       22.5000
  23.6400       7.3100        8.0646         .0100       23.0000
  23.5900       7.2800        8.0723        0.0000       23.5000
  23.6400       7.3000        8.0646        0.0000       24.0000

     °C          mg/1          mg/1      langleys/hour
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************************************************************
JAMES RIVER      JUP    13 SEPTEMBER 1974

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 TEMPERATURE  OXYGEN        SATURATION   RADIATION     TIME
 23.6400       7.3000        8.0646       0.0000       0.0000
 23.7000       7.4200        8.0554       -.0100        .5000
 23.7600       7.5100        8.0463       -.0100       1.0000
 23.7600       7.5500        8.0463       -.0100       1.5000
 23.7200       7.5200        8.0524       -.0100       2.0000
 23.6500       7.4800        8.0631       -.0100       2.5000
 23.6200       7.3900        8.0677       -.0100       3.0000
 23.6100       7.3600        8.0692       -.0100       3.5000
 23.6100       7.3300        8.0692       -.0100       4.0000
 23.6200       7.3000        8.0677       -.0100       4.5000
 23.6500       7.2600        8.0631       -.0100       5.0000
 23.6700       7.2400        8.0600       -.0100       5.5000
 23.6700       7.2200        8.0600       -.0100       6.0000
 23.6600       7.1900        8.0616       -.0100       6.5000
 23.6800       7.1400        8.0585       -.0100       7.0000
 23.6500       7.1100        8.0631        .0100       7.5000
 23.6200       7.0600        8.0677        .0400       8.0000
 23.6500       7.0100        8.0631        .1300       8.5000
 23.7000       7.0100        8.0554        .3600       9.0000
 23.7800       7.0100        8.0432        .5100       9.5000
 23.8800       7.0300        8.0280        .6600      10.0000
 24.0200       7.0700        8.0067        .8200      10.5000
 24.1700       7.1200        7.9840        .9300      11.0000
 24.4000       7.2100        7.9494       1.0400      11.5000
 24.5600       7.3300        7.9255       1.1200      12.0000
 24.8000       7.4100        7.8898       1.1800      12.5000
 25.0600       7.5100        7.8485       1.2100      13.0000
 25.2500       7.6400        7.8236       1.2300      13.5000
 25.4100       7.7300        7.8003       1.2100      14.0000
 25.6500       7.9200        7.7656       1.2000      14.5000
 25.8200       8.0600        7.7413        .9900      15.0000
 26.1400       8.2500        7.6956        .9800      15.5000
 26.1100       8.2800        7.7000        .6900      16.0000
 25.7500       7.9900        7.7513        .3600      16.5000
 25.4300       7.6600        7.7974        .6000      17.0000
 25.0000       7.3700        7.8603        .5500      17.5000
 24.7900       7.4600        7.8913        .2900      18.0000
 24.7700       7.7800        7.8942        .2400      18.5000
 24.6800       7.7100        7.9076        .0800      19.0000
 24.5200       7.6200        7.9314        .0400      19.5000
 24.4300       7.5400        7.9449        .0200      20.0000
 24.3400       7.3500        7.9524        .0200      20.5000
 24.2400       7.2500        7.9734        .0200      21.0000
 24.2100       7.0400        7.9780        .0200      21.5000
 24.1700       6.8700        7.9840        .0100      22.0000
 24.1700       6.7400        7.9840       0.0000      22.5000
 24.1500       6.6400        7.9870       0.0000      23.0000
 24.1400       6.6200        7.9885      -0.0000      23.5000
 24.1300       6.6700        7.9900       0.0000      24.0000
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°C   mg/l   mg/l   langleys/hour

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*************************************************************
JAMES RIVER      JUP    15 SEPTEMBER 1974

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 TEMPERATURE  OXYGEN          SATURATION     RADIATION      TIME
 23.3900       7.9500          8.1031         0.0000        0.0000
 23.3300       7.9700          8.1123        -0.0000         .5000
 23.3200       8.0600          8.1139        -0.0000        1.0000
 23.3300       8.1200          8.1123        -0.0000        1.5000
 23.3200       8.0600          8.1139        -0.0000        2.0000
 23.2700       7.9700          8.1216        -0.0000        2.5000
 23.2200       7.9100          8.1294        -0.0000        3.0000
 23.1700       7.8900          8.1371        -0.0000        3.5000
 23.1600       7.8400          8.1387        -0.0000        4.0000
 23.1500       7.8100          8.1402        -0.0000        4.5000
 23.1500       7.7800          8.1402        -0.0000        5.0000
 23.0900       7.7700          8.1496        -0.0000        5.5000
 23.0700       7.7300          8.1527        -0.0000        6.0000
 23.0700       7.6600          8.1527        -0.0000        6.5000
 23.0200       7.6300          8.1605         0.0000        7.0000
 23.0600       7.5600          8.1542          .0100        7.5000
 23.0200       7.5300          8.1605          .0300        8.0000
 23.0000       7.4900          8.1636          .0600        8.5000
 22.9800       7.4600          8.1667          .1100        9.0000
 22.9800       7.4700          8.1667          .1700        9.5000
 22.9700       7.4900          8.1683          .2400       10.0000
 23.0000       7.5100          8.1636          .3100       10.5000
 23.0000       7.5500          8.1636          .2600       11.0000
 23.0000       7.6100          8.1656          .3100       11.5000
 23.0500       7.6700          8.1558          .3300       12.0000
 23.1000       7.7900          8.1480          .6000       12.5000
 23.1300       7.9100          8.1433          .7200       13.0000
 23.2200       8.0300          8.1294          .9800       13.5000
 23.3100       8.1600          8.1154          .8600       14.0000
 23.3900       8.3200          8.1031          .7000       14.5000
 23.4200       8.4600          8.0985          .4100       15.0000
 23.4400       8.5300          8.0954          .3800       15.5000
 23.4500       8.5900          8.0938          .3900       16.0000
 23.4500       8.6700          8.0938          .3400       16.5000
 23.4300       8.6500          8.0969          .4300       17.0000
 23.3800       8.6100          8.1046          .4300       17.5000
 23.3200       8.5600          8.1139          .3600       18.0000
 23.2300       8.5100          8.1278          .1900       18.5000
 23.2000       8.4500          8.1325          .0800       19.0000
 23.1000       8.4500          8.1480          .0300       19.5000
 23.0700       8.4600          8.1527         0.0000       20.0000
 22.9700       8.4000          8.1683        -0.0000       20.5000
 22.8400       8.2500          8.1886         -.0100       21.0000
 22.7400       8.0900          8.2043         -.0100       21.5000
 22.6400       8.0000          8.2200         -.0100       22.0000
 22.5800       7.9700          8.2294         -.0100       22.5000
 22.5700       7.9600          8.2310         -.0100       23.0000
 22.5300       8.0100          8.2373         -.0100       23.5000
 22.5100       8.0700          8.2405         0.0000       24.0000

    °C          mg/1            mg/1       langleys/hour
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*********************************************************************
 JAMES RIVER      JUP     16 SEPTEMBER 1974

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 TEMPERATURE   OXYGEN        SATURATION    RADIATION     TIME
  22.5100       8.0700        8.2405        0.0000        0.0000
  22.5400       8.1200        8.2357       -0.0000         .5000
  22.5000       8.1400        8.2421       -0.0000        1.0000
  22.4600       8.0500        8.2454       -0.0000        1.5000
  22.4100       8.0300        8.2563       -0.0000        2.0000
  22.3700       7.9900        8.2626       -0.0000        2.5000
  22.3700       7.9400        8.2626       -0.0000        3.0000
  22.3600       7.8700        8.2642       -0.0000        3.5000
  22.3400       7.8400        8.2674       -0.0000        4.0000
  22.3300       7.8200        8.2690        0.0000        4.5000
  22.3400       7.8000        8.2674        0.0000        5.0000
  22.3200       7.7600        8.2706        0.0000        5.5000
  22.2900       7.7400        8.2753       -0.0000        6.0000
  22.2400       7.7200        8.2833       -0.0000        6.5000
  22.2000       7.6500        8.2896       -0.0000        7.0000
  22.1400       7.6400        8.2992         .0200        7.5000
  22.0900       7.6100        8.3072         .0500        8.0000
  22.0600       7.6100        8.3119         .1300        8.5000
  22.0800       7.6400        8.3088         .3700        9.0000
  22.1300       7.6700        8.3008         .5800        9.5000
  22.2200       7.7400        8.2864         .7500       10.0000
  22.3100       7.8300        8.2721         .8700       10.5000
  22.4200       7.9200        8.2547         .9800       11.0000
  22.6000       8.0600        8.2263        1.0600       11.5000
  22.8400       8.2100        8.1886        1.1100       12.0000
  23.0000       8.3400        8.1636        1.2000       12.5000
  23.1500       8.5700        8.1402        1.2500       13.0000
  23.3400       8.7000        8.1108        1.2500       13.5000
  23.5300       8.8400        8.0815        1.2000       14.0000
  23.7000       8.9600        8.0554        1.1400       14.5000
  23.8100       9.0900        8.0386        1.0700       15.0000
  24.0100       9.1400        8.0082         .9600       15.5000
  24.0700       9.3600        7.9991         .8900       16.0000
  24.1900       9.4200        7.9810         .4900       16.5000
  24.2900       9.5600        7.9659         .3300       17.0000
  24.3600       9.5900        7.9554         .2500       17.5000
  24.3400       9.5700        7.9584         .1500       18.0000
  24.3100       9.5400        7.9629         .0900       18.5000
  24.2800       9.4700        7.9674         .0500       19.0000
  24.1700       9.4300        7.9840         .0300       19.5000
  24.0700       9.2600        7.9991         .0200       20.0000
  23.9500       9.1100        8.0173         .0100       20.5000
  23.7700       8.9500        8.0447         .0100       21.0000
  23.6500       8.7200        8.0631         .0100       21.5000
  23.5700       8.6700        8.0754         .0100       22.0000
  23.4200       8.5200        8.0985         .0100       22.5000
  23.2800       8.4000        8.1201         .0100       23.0000
  23.1400       8.3300        8.1416         .0100       23.5000
  22.9800       8.2400        8.1657        0.0000       24.0000

    °C           mg/l          mg/l       langleys/hour
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*************************************************
JAMES RIVER      JUP    17 SEPTEMBER 1974

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TEMPERATURE   OXYGEN          SATURATION     RADIATION        TIME
 22.9800        8.2400          8.1667         0.0000          0.0000
 22.8800        8.1400          8.1823        -0.0000           .5000
 22.7700        8.1600          8.1996        -0.0000          1.0000
 22.7800        8.3200          8.1930        -0.0000          1.5000
 22.8700        8.5000          8.1839        -0.0000          2.0000
 22.9700        8.8100          8.1683        -0.0000          2.5000
 23.0000        8.9300          8.1636        -0.0000          3.0000
 22.9200        8.9700          8.1761        -0.0000          3.5000
 22.8300        8.9300          8.1901        -0.0000          4.0000
 22.7400        8.7800          8.2043        -0.0000          4.5000
 22.6900        8.6900          8.2121        -0.0000          5.0000
 22.6400        8.6700          8.2200        -0.0000          5.5000
 22.6300        8.6200          8.2216        -0.0000          6.0000
 22.6300        8.6100          8.2216        -0.0000          6.5000
 22.6100        8.5600          8.2247         0.0000          7.0000
 22.6000        8.5500          8.2263          .0200          7.5000
 22.6000        8.5100          8.2263          .0700          8.0000
 22.6000        8.5100          8.2263          .1500          8.5000
 22.6000        8.4600          8.2263          .1500          9.0000
 22.6000        8.4500          8.2263          .1300          9.5000
 22.6000        8.4200          8.2263          .2000         10.0000
 22.6100        8.4300          8.2247          .2700         10.5000
 22.7100        8.4800          8.2090          .5400         11.0000
 22.7800        8.5600          8.1980          .6600         11.5000
 22.8700        8.7200          8.1839          .5500         12.0000
 22.9700        8.8800          8.1683          .6300         12.5000
 23.0100        8.9200          8.1620          .3600         13.0000
 23.0600        9.0300          8.1511          .4000         13.5000
 23.0800        9.0800          8.1511          .2900         14.0000
 23.1300        9.2200          8.1433          .2300         14.5000
 23.2000        9.3600          8.1325          .2700         15.0000
 23.2600        9.4900          8.1232          .3500         15.5000
 23.3200        9.5500          8.1139          .2600         16.0000
 23.3400        9.5600          8.1108          .1900         16.5000
 23.3300        9.5900          8.1123          .1900         17.0000
 23.3100        9.5200          8.1154          .1400         17.5000
 23.2600        9.3400          8.1232          .1100         18.0000
 23.2300        9.2800          8.1278          .1700         18.5000
 23.1700        9.2700          8.1371          .0900         19.0000
 23.1700        9.2700          8.1371          .0300         19.5000
 23.1600        9.3000          8.1387          .0100         20.0000
 23.1500        9.1600          8.1402          .0100         20.5000
 23.0400        9.0000          8.1573          .0100         21.0000
 22.9000        8.7300          8.1792         0.0000         21.5000
 22.7700        8.4700          8.1996        -0.0000         22.0000
 22.6300        8.3600          8.2216        -0.0000         22.5000
 22.5000        8.4600          8.2421        -0.0000         23.0000
 22.4800        8.5700          8.2452         0.0000         23.5000
 22.4300        8.8100          8.2531         0.0000         24.0000
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°C   mg/1   mg/1   langleys/hour

Appendix C. Printouts of primary productivity estimated for the James River, August 25 and 26 1974.

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REAERATION COEFFICIENT WAS ESTIMATED FROM THE LIGHT/PRODUCTIVITY RELATIONSHIP AND THE NIGHTTIME RESPIRATION.

IF THE ESTIMATES DIFFER BY MORE THAN      .0500 OUTPUTS FOR THE LIGHT AND POST-SUNSET RESPIRATION
ESTIMATES WILL BE GIVEN. OTHERWISE ONLY THE LIGHT ESTIMATE WILL BE USED.


 ESTIMATE OF REAERATION COEFFICIENT FROM THE LIGHT/PRODUCTIVITY RELATIONSHIP :

ESTIMATED REAERATION COEFFICIENT=          .1367

ESTIMATED SLOPE OF LIGHT/PRODUCTIVITY=      .9412E-02 GRAMS OXYGEN PER CUBIC METER PER LANGLEY

ESTIMATED DAYTIME RESPIRATION=          .0483 GRAMS OXYGEN PER CUBIC METER PER HOUR


ESTIMATES OF REAERATION COEFFICIENT FROM NIGHTTIME RESPIRATION :

PREDAWN ESTIMATE:

ESTIMATED REAERATION COEFFICIENT =      .3108

ESTIMATED NIGHTTIME RESPIRATION =     -.4790      GRAMS OXYGEN PER CUBIC METER PER HOUR

POST-SUNSET ESTIMATE:

ESTIMATED REAERATION COEFFICIENT =      .2641

ESTIMATED NIGHTTIME RESPIRATION =     -.3746      GRAMS OXYGEN PER CUBIC METER PER HOUR
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     NET PRODUCTIVITY CALCULATED BY THE SINGLE STATION METHOD

    ************************************************************
      JAMES RIVER     JUP    26 AUGUST 1974
    ************************************************************
      OUTPUT         NO. DATA      DATA POINTS       REAERATION       BAROMETRIC
      INTERVAL       POINTS        PER INTERVAL      COEFFICIENT      PRESSURE
       .5 HRS          49               2            .14 PER HR        950.00

    COEFFICIENT VALUES-
       1     .51108227E-01
       2   -.25471772E-01
       3   -.52507410E+00
       4     .12933565E+00
       5     .70938693E-01
       6   -.71710974E-01
       7     .53392589E-01
       8   -.21332088E-01

    ************************************************************
                         OXYGEN GRAMS PER CUBIC METER
      TIME      PREDICTED             OBSERVED
        .50       7.2273               7.1500
       1.00       7.0432               7.0400
       1.50       6.9166               6.9400
       2.00       6.8285               6.8300
       2.50       6.7321               6.7600
       3.00       6.6746               6.7000
       3.50       6.6280               6.6500
       4.00       6.5924               6.5600
       4.50       6.5401               6.5100
       5.00       6.4903               6.4700
       5.50       6.4711               6.4400
       6.00       6.4643               6.5000
       6.50       6.5442               6.5400
       7.00       6.6081               6.6300
       7.50       6.7209               6.7100
       8.00       6.8255               6.8200
       8.50       6.9587               6.9600
       9.00       7.1199               7.1300
       9.50       7.3083               7.3200
      10.00       7.5142               7.5500
      10.50       7.7562               7.7400
      11.00       7.9593               7.9400
      11.50       8.0761               8.1200
      12.00       8.3514               8.4100
      12.50       8.6473               8.6900
      13.00       8.9244               8.8600
      13.50       9.0946               9.0900
      14.00       9.3146               9.3200
      14.50       9.5272               9.5000
      15.00       9.6647               9.7100
      15.50       9.8596               9.9000
      16.00      10.0047              10.1200
      16.50      10.1677               9.9900
      17.00       9.9950               9.9800
      17.50       9.9274               9.9800
      18.00       9.8652               9.8000
      18.50       9.6347               9.6500
      19.00       9.4453               9.4900
      19.50       9.2354               9.2600
      20.00       8.9602               8.9100
      20.50       8.6247               8.6900
      21.00       8.4029               8.5600
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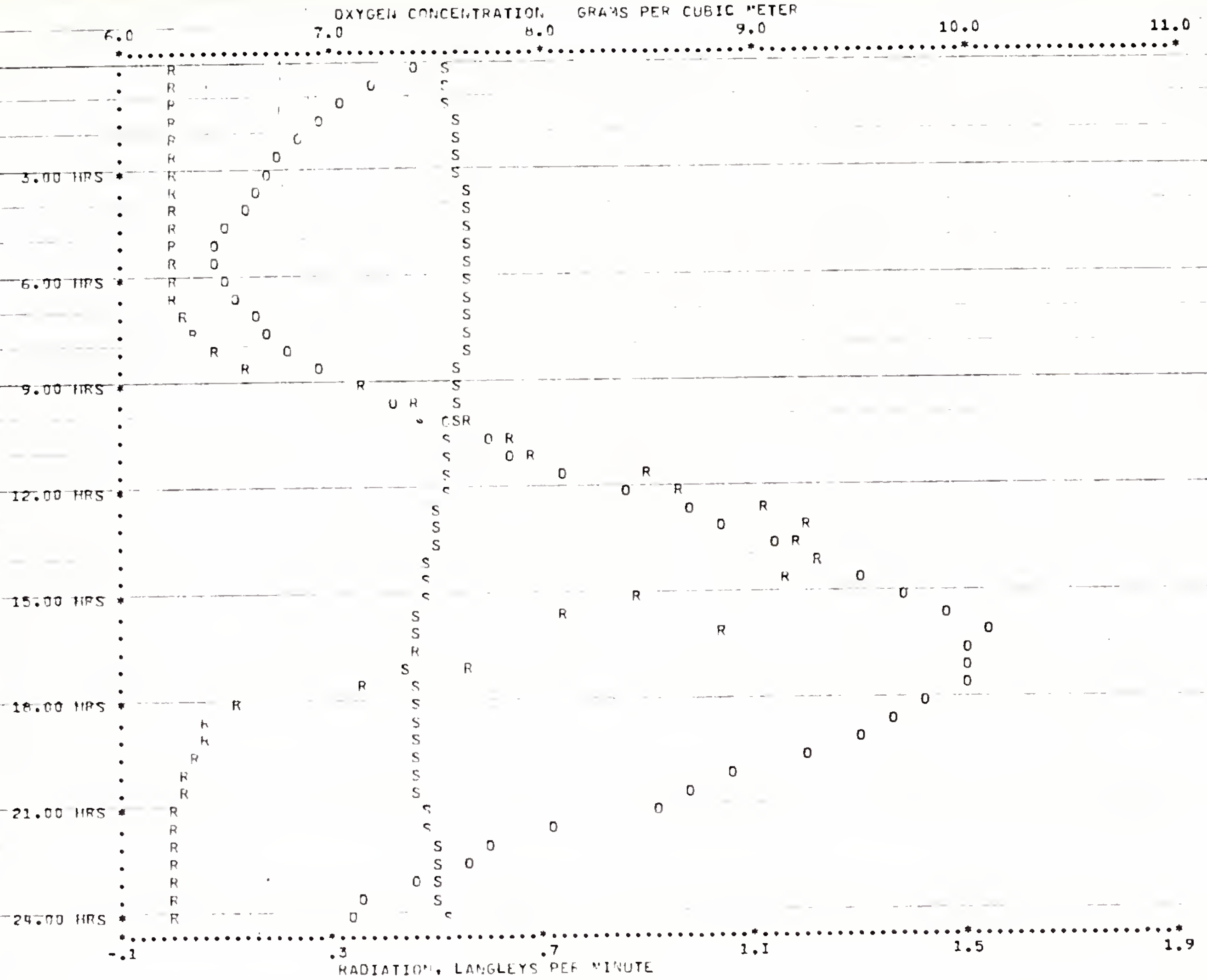
      21.50         8.2767              8.0700
      22.00         7.8232              7.7400
      22.50         7.5244              7.6400
      23.00         7.4417              7.3600
      23.50         7.2086              7.1400
      24.00         6.9904              7.1100

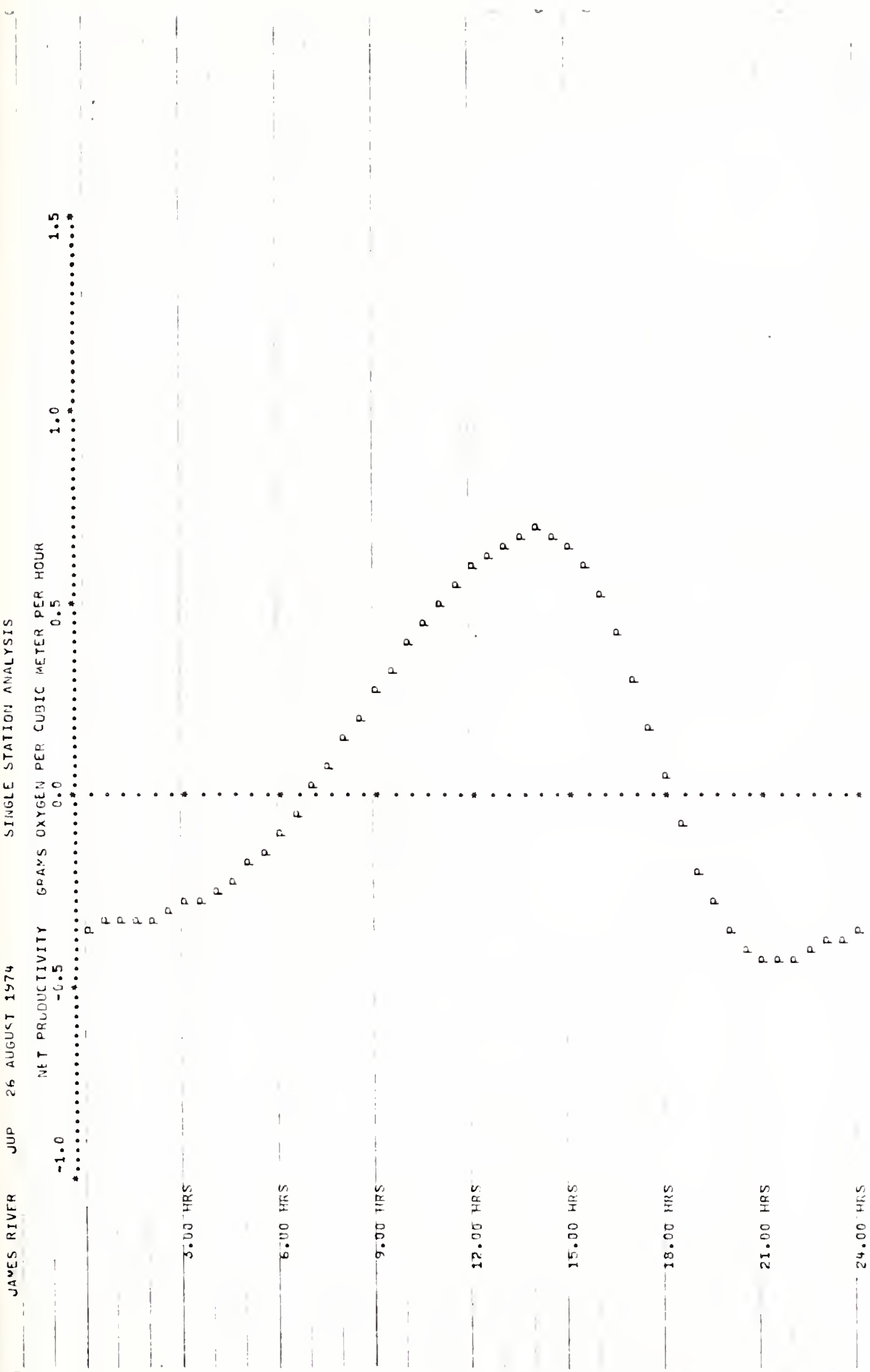
    SUM OF SQUARED ERRORS=  .2138166E+00

       TIME          P-R   GRAMS OXYGEN PER CUBIC METER PER HOUR
       0.00         -.3388
        .50         -.3372
       1.00         -.3325
       1.50         -.3248
       2.00         -.3143
       2.50         -.3010
       3.00         -.2846
       3.50         -.2653
       4.00         -.2418
       4.50         -.2135
       5.00         -.1798
       5.50         -.1399
       6.00         -.0937
       6.50         -.0413
       7.00          .0165
       7.50          .0785
       8.00          .1430
       8.50          .2083
       9.00          .2728
       9.50          .3352
      10.00          .3946
      10.50          .4504
      11.00          .5024
      11.50          .5504
      12.00          .5937
      12.50          .6314
      13.00          .6615
      13.50          .6815
      14.00          .6660
      14.50          .6777
      15.00          .6475
      15.50          .5951
      16.00          .5202
      16.50          .4239
      17.00          .3101
      17.50          .1844
      18.00          .0540
      18.50         -.0728
      19.00         -.1882
      19.50         -.2651
      20.00         -.3588
      20.50         -.4072
      21.00         -.4310
      21.50         -.4340
      22.00         -.4220
      22.50         -.4020
      23.00         -.3812
      23.50         -.3660
      24.00         -.3605

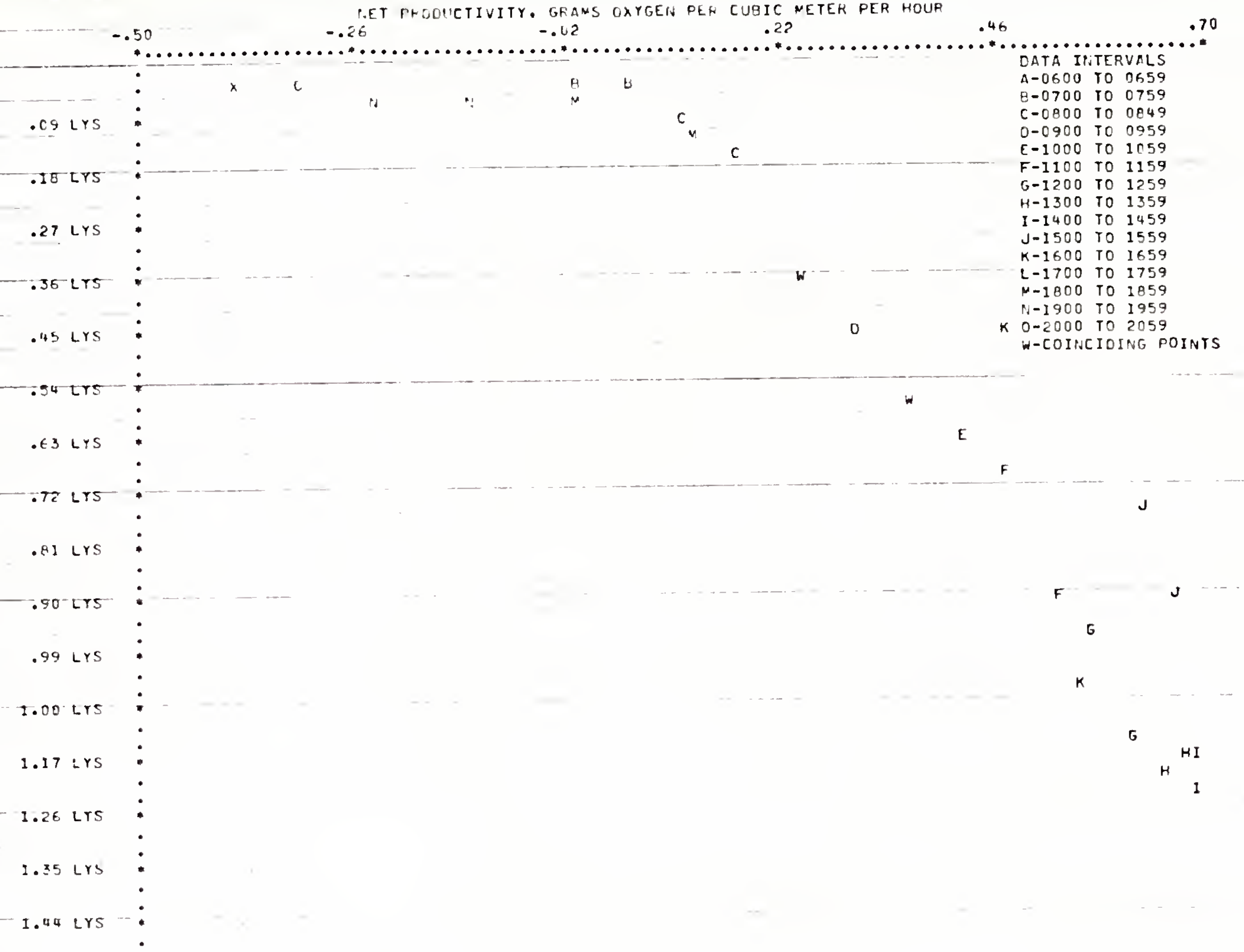
     SUMMARY FOR DAY: PRODUCTION AND RESPIRATION IN GRAMS O2 PER CUBIC METER PER DAY, RADIATION IN LANGLEYS
    NET PRODUCTION=   1.23   RESPIRATION=  -6.60   GROSS PRODUCTION=   7.83   TOTAL RADIATION= 455.10
```

JAMES RIVER   JUP   26 AUGUST 1974   OXYGEN, SATURATION AND RADIATION DATA




JAMES RIVER
JUP
26 AUGUST 1974
SINGLE STATION ANALYSIS
NET PRODUCTIVITY
GRAMS OXYGEN PER CUBIC METER PER HOUR
-1.0
-0.5
0.0
0.5
1.0
1.5
3.00 HRS
6.00 HRS
9.00 HRS
12.00 HRS
15.00 HRS
18.00 HRS
21.00 HRS
24.00 HRS

NET PRODUCTIVITY VERSUS RADIATION



INTERCEPT- -.064 SLOPE= .6790 CORRELATION COEFFICIENT= .914

```
*****     SUMMARY     *****        JAMES RIVER     JUP    26 AUGUST 1974

SINGLE STATION ANALYSIS

            REAERATION-  .14     PARAMETERS- 8     RESIDENCE TIME-  .50 HRS

                        NET PRODUCTION         1.23    GRAMS OXYGEN PER CUBIC METER PER DAY
                        RESPIRATION-          -6.60    GRAMS OXYGEN PER CUBIC METER PER DAY
                        GROSS PRODUCTION-      7.83    GRAMS OXYGEN PER CUBIC METER PER DAY
                        TOTAL RADIATION-     455.10    LANGLEYS

                        SLOPE-        .172E-01     (RATIO OF GROSS PROD. TO TOTAL RAD.)    GRAMS OXYGEN PER CUBIC METER PER LANGLEY
                                      .113E-01     (FROM REGRESSION)     GRAMS OXYGEN PER  CUBIC METER PER LANGLEY
                        INTERCEPT-     -.064   GRAMS OXYGEN PER CUBIC METER PER HOUR       -1.546  PER DAY
                        CORRELATION-    .914
```

```
REAERATION COEFFICIENT WAS ESTIMATED FROM THE LIGHT/PRODUCTIVITY RELATIONSHIP AND THE NIGHTTIME RESPIRATION.

IF THE ESTIMATES DIFFER BY MORE THAN      .0500 OUTPUTS FOR THE LIGHT AND POST-SUNSET RESPIRATION
ESTIMATES WILL BE GIVEN. OTHERWISE ONLY THE LIGHT ESTIMATE WILL BE USED.


ESTIMATE OF REAERATION COEFFICIENT FROM THE LIGHT/PRODUCTIVITY RELATIONSHIP :

ESTIMATED REAERATION COEFFICIENT=           .2148

ESTIMATED SLOPE OF LIGHT/PRODUCTIVITY=      .1550E-01 GRAMS OXYGEN PER CUBIC METER PER LANGLEY

ESTIMATED DAYTIME RESPIRATION=         -.1055 GRAMS OXYGEN PER CUBIC METER PER HOUR


ESTIMATES OF REAERATION COEFFICIENT FROM NIGHTTIME RESPIRATION :

PREDAWN ESTIMATE:

ESTIMATED REAERATION COEFFICIENT =      .3146

ESTIMATED NIGHTTIME RESPIRATION =      -.4613     GRAMS OXYGEN PER CUBIC METER PER HOUR

POST-SUNSET ESTIMATE:

ESTIMATED REAERATION COEFFICIENT =      .0575

ESTIMATED NIGHTTIME RESPIRATION =      -.5242     GRAMS OXYGEN PER CUBIC METER PER HOUR
```

```
     NET PRODUCTIVITY CALCULATED BY THE SINGLE STATION METHOD

   ****************************************************
    JAMES RIVER     JUP    25 AUGUST 1974

   ****************************************************
    OUTPUT        NO. DATA      DATA POINTS     REAERATION      BAROMETRIC
    INTERVAL      POINTS        PER INTERVAL    COEFFICIENT     PRESSURE
      .5 HRS        49              2            .21 PER HR       950.00

   COEFFICIENT VALUES-
      1     .19299566E+00
      2    -.13827106E+00
      3    -.79615024E+00
      4     .22426209E+00
      5     .17503590E+00
      6     .50212367E-01
      7    -.98017000E-01
      8    -.93402424E-01

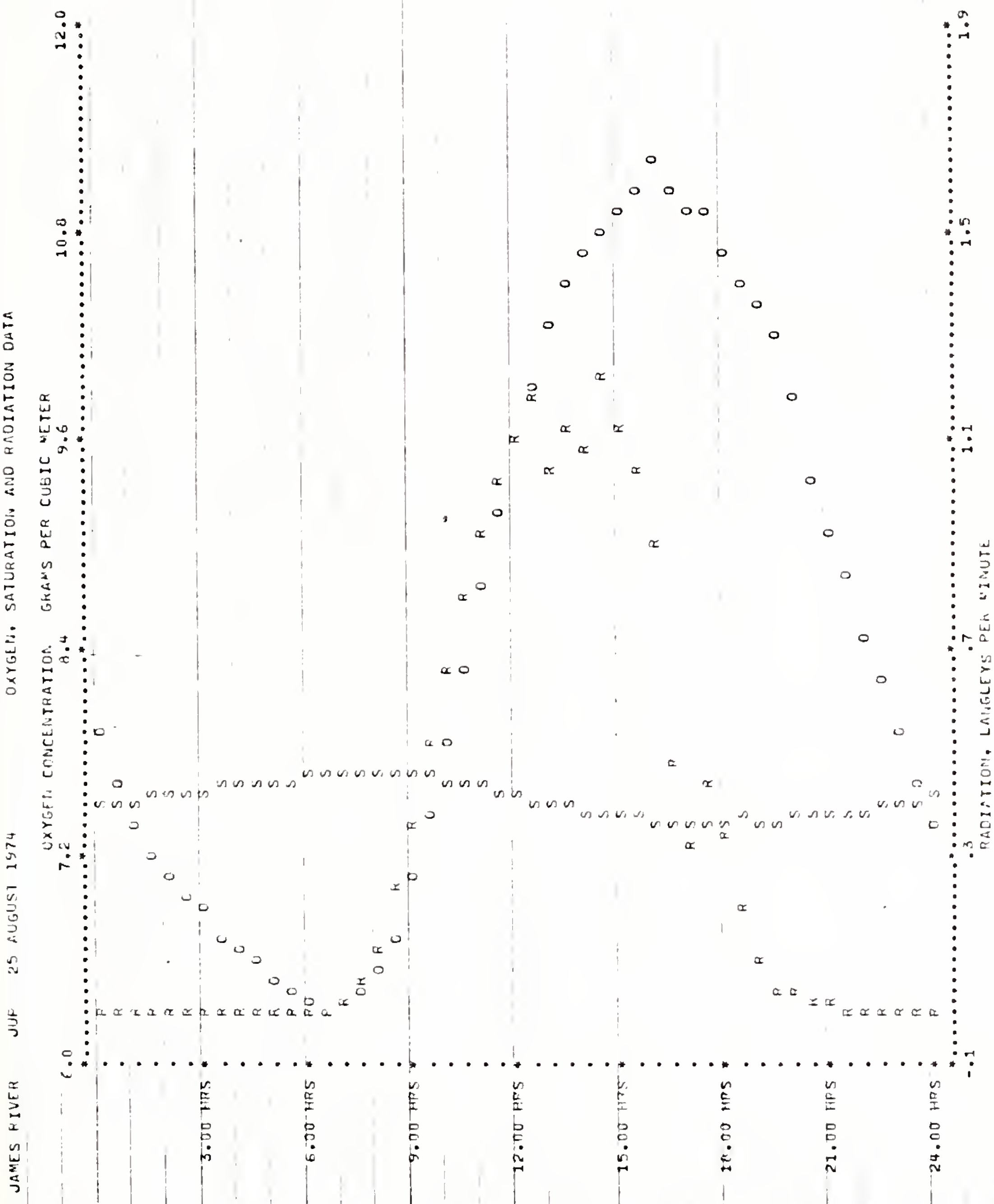
   ****************************************************
                        OXYGEN GRAMS PER CUBIC METER
     TIME      PREDICTED                 OBSERVED
      .50         7.6765                   7.6400
     1.00         7.4066                   7.4000
     1.50         7.2048                   7.2100
     2.00         7.0500                   7.0900
     2.50         6.9571                   6.9800
     3.00         6.8688                   6.8700
     3.50         6.7739                   6.7500
     4.00         6.6639                   6.6500
     4.50         6.5678                   6.5600
     5.00         6.4978                   6.5100
     5.50         6.4324                   6.4300
     6.00         6.3604                   6.3600
     6.50         6.3280                   6.3200
     7.00         6.3330                   6.3500
     7.50         6.4204                   6.4200
     8.00         6.5607                   6.5200
     8.50         6.7412                   6.7200
     9.00         7.0179                   7.0500
     9.50         7.4105                   7.4600
    10.00         7.8669                   7.8600
    10.50         8.2995                   8.2900
    11.00         8.7407                   8.7500
    11.50         9.1878                   9.1600
    12.00         9.5694                   9.6000
    12.50         9.9605                   9.9300
    13.00        10.2465                  10.2400
    13.50        10.4947                  10.4800
    14.00        10.6805                  10.6700
    14.50        10.8206                  10.8000
    15.00        10.9076                  10.9000
    15.50        10.9677                  11.0300
    16.00        11.0538                  11.2300
    16.50        11.0603                  11.0700
    17.00        11.0186                  10.9300
    17.50        10.8475                  10.9000
    18.00        10.7674                  10.8600
    18.50        10.4922                  10.5200
    19.00        10.3024                  10.3600
    19.50        10.0934                  10.2100
    20.00         9.8970                   9.8500
    20.50         9.5192                   9.3900
    21.00         9.0667                   9.0600
```

```
     21.50      8.7255          [illegible]
     22.00      8.4721          8.4690
     22.50      8.1704          8.2100
     23.00      7.9209          7.9100
     23.50      7.6489          7.6100
     24.00      7.3791          7.3800

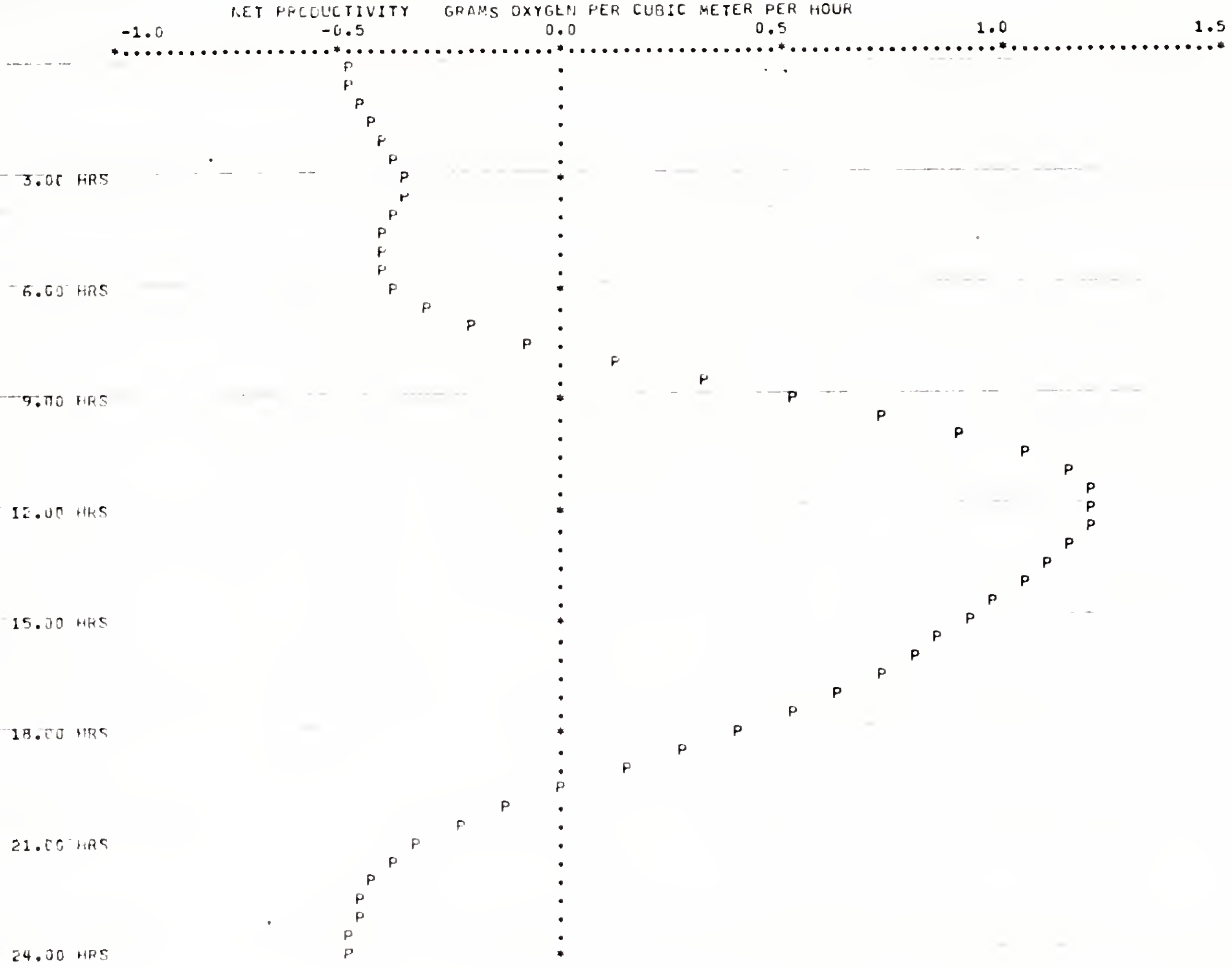
  SUM OF SQUARED ERRORS=  .1331529E+00

      TIME        P-R   GRAMS OXYGEN PER CUBIC METER PER HOUR
      0.00      -.4839
       .50      -.4764
      1.00      -.4555
      1.50      -.4263
      2.00      -.3957
      2.50      -.3709
      3.00      -.3576
      3.50      -.3582
      4.00      -.3708
      4.50      -.3893
      5.00      -.4041
      5.50      -.4034
      6.00      -.3759
      6.50      -.3124
      7.00      -.2080
      7.50      -.0635
      8.00       .1149
      8.50       .3158
      9.00       .5243
      9.50       .7243
     10.00       .9008
     10.50      1.0421
     11.00      1.1412
     11.50      1.1966
     12.00      1.2116
     12.50      1.1938
     13.00      1.1527
     13.50      1.0961
     14.00      1.0380
     14.50       .9776
     15.00       .9165
     15.50       .8590
     16.00       .7949
     16.50       .7214
     17.00       .6339
     17.50       .5301
     18.00       .4106
     18.50       .2790
     19.00       .1415
     19.50       .0160
     20.00      -.1195
     20.50      -.2282
     21.00      -.3156
     21.50      -.3802
     22.00      -.4235
     22.50      -.4492
     23.00      -.4625
     23.50      -.4681
     24.00      -.4695

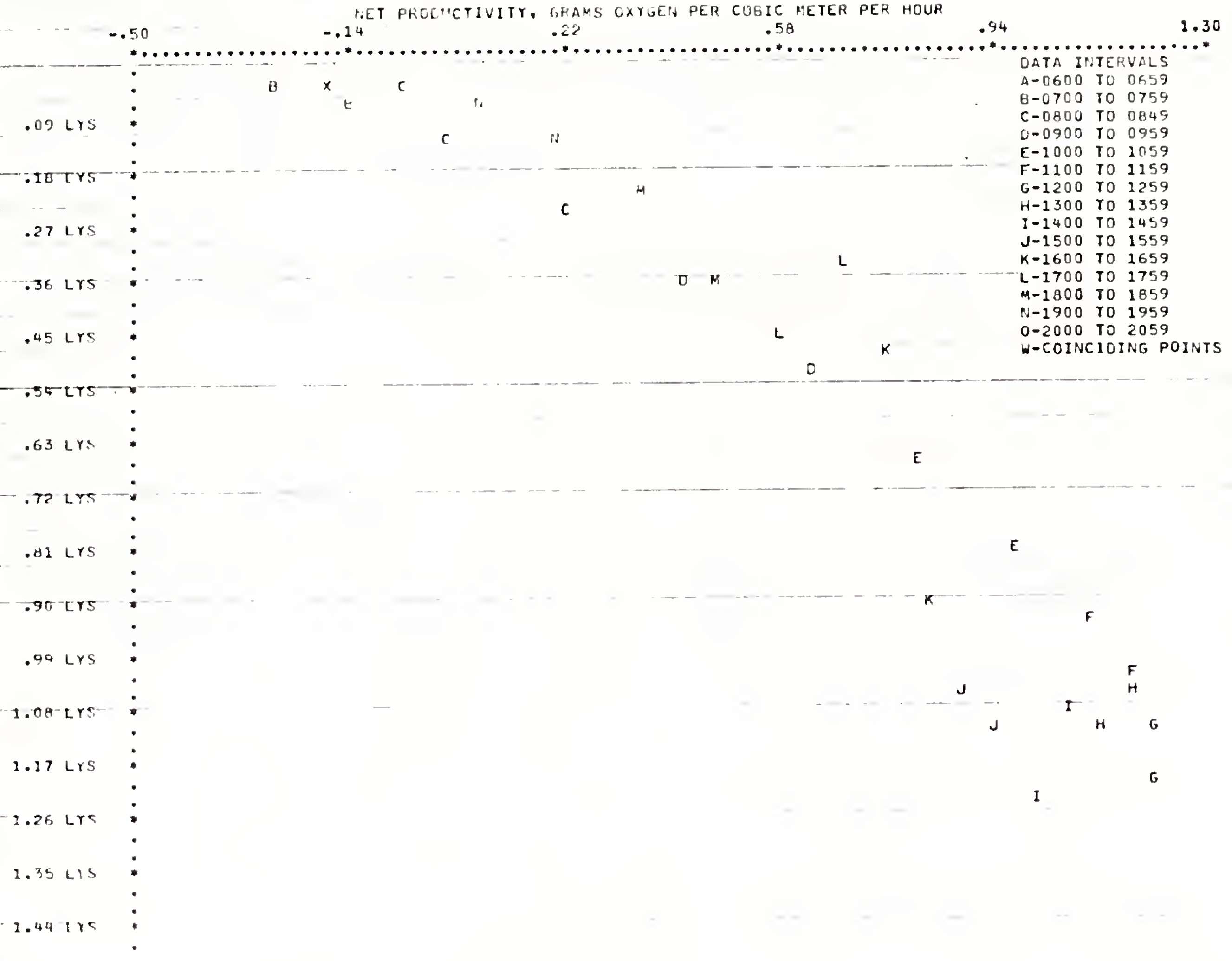
   SUMMARY FOR DAY: PRODUCTION AND RESPIRATION IN GRAMS O2 PER CUBIC METER PER DAY, RADIATION IN LANGLEYS
  NET PRODUCTION=   4.62   RESPIRATION=  -9.04   GROSS PRODUCTION=  13.66   TOTAL RADIATION= 497.55
```


JAMES RIVER JUF 25 AUGUST 1974 OXYGEN, SATURATION AND RADIATION DATA
OXYGEN CONCENTRATION, GRAMS PER CUBIC METER
6.0
7.2
8.4
9.6
10.8
12.0
3.00 HRS
6.00 HRS
9.00 HRS
12.00 HRS
15.00 HRS
18.00 HRS
21.00 HRS
24.00 HRS
-.1
.3
.7
1.1
1.5
1.9
RADIATION, LANGLEYS PER MINUTE

JAMES RIVER JUP 25 AUGUST 1974 SINGLE STATION ANALYSIS



NET PRODUCTIVITY VERSUS RADIATION



INTERCEPT- .007 SLOPE= 1.0268 CORRELATION COEFFICIENT= .943

```
*****     SUMMARY     *****        JAMES RIVER     JUP    25 AUGUST 1974

   SINGLE STATION ANALYSIS

             REAERATION-   .21      PARAMETERS- 8      RESIDENCE TIME-   .50 HRS

                         NET PRODUCTION        4.62    GRAMS OXYGEN PER CUBIC METER PER DAY
                         RESPIRATION-         -9.04    GRAMS OXYGEN PER CUBIC METER PER DAY
                         GROSS PRODUCTION-   17.66    GRAMS OXYGEN PER CUBIC METER PER DAY
                         TOTAL RADIATION-   497.55    LANGLEYS

                         SLOPN-         .275E-01      (RATIO OF GROSS PROD. TO TOTAL RAD.)    GRAMS OXYGEN PER CUBIC METER PER LANGLEY
                                        .171E-01      (FROM REGRESSION)      GRAMS OXYGEN PER  CUBIC METER PER LANGLEY
                         INTERCEPT-       .007    GRAMS OXYGEN PER CUBIC METER PER HOUR         .180   PER DAY
                         CORRELATION-     .947
```

APPENDIX D. MACROINVERTEBRATE TABLES & FIGURES

Table 10. Macroinvertebrates collected from the James River from Riverville downstream to Wingina, Virginia during the period March 1974 thru July 1975.

	001	002	003	004	005	006
Phylum Platyhelminthes						
Class Turbellaria						
Order Tricladia						
Family Planariidae:						
Cura foremanii	X	X	X	X	X	X
Curtisia sp.				X	X	X
Hymanalla sp.		X				
Macrostomum sp.		X				
Dugesia sp.	X	X	X	X	X	X
Phagocata sp.	X	X		X	X	X
Phylum Annelida						
Class Hirudinea						
Order Pharynogobdellida						
Family Erpobdellidae:						
Erpobdella sp.	X					
Order Rhynchobdellida						
Family Glossiphoniidae:				X		
Actinobdella sp.				X		
Batracobdella sp.	X			X	X	X
Helobdella sp.		X	X			
Marvinmeyeria lucidia				X		
Placobdella sp.	X					
Class Oligochaeta						
Order Plesiopora	X					
Family Aeolosomatidae:						
Aeolosoma sp.	X	X	X	X	X	X
Family Enchytraeidae:	X					
Family Naididae:						
Nais sp.		X		X	X	
Ophidonais serpentina				X		
Family Tubificidae:						
Branchiura sowerbyi		X				X
Limnodrilus sp.					X	
Tubifex sp.	X		X		X	
Order Prospora						
Family Branchiobdellidae:		X				
Family Lumbriculidae:	X	X	X	X	X	X
Order Opisthopora						
Family Lumbricidae:	X					
Phylum Molluska						
Class Gastropoda						
Order Basommatophora (Pulmonata)						
Family Ancylidae:						
Laevapex fuseus	X	X	X	X	X	X

Table 10. (Continued)

	001	002	003	004	005	006
Family Physidae:						
Physa sp.	X	X	X	X	X	X
Family Planorbidae:						
Gyralus Sp.	X	X	X			
Helisoma Sp.	X	X	X		X	
Family Lymnaeidae:						
Lymnaea sp.	X	X	X			
Order Mesogastropoda						
Family Hydrobiidae:						
Amnicola sp.	X	X	X	X	X	
Hydrobia sp.				X		
Somatogyrus sp.			X	X		
Family Pleuroceridae:						
Goniobasis virginica	X		X	X	X	
Pleurocera sp.		X	X	X	X	X
Spirodon carinata		X	X	X	X	X
Family Valvatidae:						
Valvata sp.	X		X	X	X	
Valvata sincera					X	
Family Viviparidae:						
Viviparus sp.		X				
Compeloma sp.		X		X	X	
Class Pelecypoda						
Order Eulamellibranchia						
Family Unionidae:						
Elliptio sp.	X	X	X	X	X	X
Order Heterodonata						
Family Sphaeriidae:						
Sphaerium sp.	X	X	X	X	X	X
Sphaerium striatinum			X		X	
Family corbiculidae						
Corbicula manilensis	X	X	X	X	X	X
Phylum Arthropoda						
Class Crustacea						
Order Amphipoda						
Family Gammaridae:						
Gammarus fasciatus	X	X	X	X	X	X
Family Hyalellidae:						
Hyalella azteca		X	X	X	X	
Order Decapoda						
Family Astacidae:						
Cambarus sp.	X	X	X			
Orconectes sp.		X	X			
Order Isopoda						
Family Asellidae:						
Asellus sp.	X	X		X	X	X
Lircerus sp.		X			X	
Class Insecta						
Order Hemiptera						
Family Gerridae:						
Rheumatobates rileyi					X	

Table 10. (Continued)

	001	002	003	004	005	006
Order Lepidoptera						
Family Pyralididae:						
Elophilia sp.		X		X		
Parargyractis sp.	X	X			X	
Order Odonata						
Family Aeshnidae:						
Aeshna sp.					X	
Anax sp.		X				
Boyeria sp.	X	X	X			
Epiaeschna heros	X					
Family Agrionidae:						
Agrion sp.	X	X				
Hetaerina sp.	X	X	X	X	X	X
Family Coenagrionidae:						
Argia sp.	X	X	X	X	X	X
Coenagrion sp.		X				
Ishnura sp.	X	X	X	X	X	X
Nehallenia sp.	X	X	X		X	X
Lestes sp.				X		
Enallagma sp.			X			
Teleallagma daecki	X					
Family Gomphidae:						
Dromogomphus sp.				X		
Gomphus sp.					X	
Hagenius brevistylus	X	X			X	
Lanthus sp.	X					X
Progomphus sp.						X
Family Libelludidae:						
Helocordulia sp.					X	
Epicordulia sp.			X			
Amphiagrion saucium			X			
Libellula sp.		X				X
Macromia sp.	X	X	X			X
Nannothemis bella	X					
Neurocordulia sp.	X	X	X	X	X	X
Trapezostigma sp.			X			
Family Petaluridae:						
Tachopteryx thoreyi	X	X				
Order Megaloptera						
Family Corydalidae:						
Chauliodes sp.	X	X	X			
Corydalus cornutus	X	X	X	X	X	X
Family Sialidae:						
Sialis sp.			X			
Order Coleoptera						
Family Elimdae:						
Ancyronyx variegata	X		X	X	X	X
Stenelmis sp.	X	X	X	X	X	X
Microcylloepus sp.	X					X
Macronychus glabratus	X	X	X	X	X	X
Dubiraphia sp.	X					X
Promoresia sp.	X	X	X	X	X	X
Oulimnius latiusculus	X			X	X	X
Optiosevus sp.						X

Table 10. (Continued)

	001	002	003	004	005	006
Family Dryopidae:						
Helichus sp.					X	X
Lutrochus sp.						X
Family Dytiscidae:						
Laccophilus sp.	X					
Family Haliplidae:						
Brychius sp.						X
Family Hydrophilidae:						
Helochares sp.			X			
Berosus sp.	X	X	X		X	X
Tropisternus sp.						X
Family Gryinidae:						
Dineutus sp.						X
Family Psephenidae:						
Ectopria nervosa			X	X	X	X
Psephnus sp.	X		X		X	X
Family Ptilodactylidae:						
Anchytarsus sp.			X			
Order Plecoptera						
Family Nemouridae:						
Nemoura sp.	X			X	X	X
Family Taeniopterygidae:						
Taeniopteryx sp.		X		X	X	X
Family Peltoperlidae:						
Peltoperla sp.		X			X	X
Family Perlidae:						
Acroneuria sp.		X				
Perlesta sp.		X		X	X	X
Family Perlodidae:						
Isoperla sp.	X			X	X	
Order Ephemeroptera						
Family Baetidae:						
Baetis sp.	X	X	X	X	X	X
Pseudocloeon sp.	X	X		X	X	X
Family Siphlonuridae:						
Isonychia sp.	X	X	X	X	X	X
Family Tricorythidae:						
Tricorythodes sp.	X	X	X	X	X	X
Family Caenidae:						
Brachycerus sp.		X				
Caenis sp.		X	X		X	X
Family Ephemerellidae:						
Ephemerella Sp.	X	X	X	X		X
Family Heptageniidae:						
Heptagenia sp.			X		X	
Stenonema sp.	X	X	X	X	X	X
Order Trichoptera						
Family Hydropsychidae:						
Cheumatopsyche sp.	X	X	X	X	X	X
Hydropsyche sp.	X	X	X	X	X	X
Macronemum sp.	X	X	X	X	X	X
Family Hydroptilidae:						
Agraylea sp.	X	X	X	X	X	X
Hydroptila sp.			X	X		
Family Leptoceridae:						
Leptocerus sp.	X		X	X	X	

Table 10. (Continued)

	001	002	003	004	005	006
Leptocella sp.	X					
Leptocella candida	X					
Oecetis sp.	X	X	X	X	X	X
Family Molannidae:						
Molanna sp.	X			X		
Family Philoptamidae:						
Chimarra Sp.	X					
Wormaldia sp.						X
Family Psychomyiidae:						
Neureclipsis sp.	X	X	X	X	X	X
Polycentropus sp.	X				X	X
Psychomyia sp.	X	X				
Order Diptera						
Family Anthomyiidae:						
Limnophera sp.					X	
Family Chironomidae:						
Ablabesmyia sp.	X	X	X	X	X	X
Brillia sp.	X		X		X	X
Cardiocladius sp.		X	X		X	X
Chironomus sp.				X	X	X
Coelotanypus sp.				X		
Constempellina sp.	X					
Cricotopus sp.	X	X	X	X	X	X
Cryptochironomus sp.		X			X	X
Diamesa sp.	X	X	X	X	X	
Dicrotendipes sp.	X	X	X		X	X
Dicrotendipes modestus		X	X		X	X
Dicrotendipes nervosus		X				
Diplocladius sp.		X	X	X		X
Einfeldia sp.	X	X			X	X
Endochironomus sp.	X	X		X	X	X
Eukiefferiella sp.	X	X	X	X	X	X
Glyptotendipes sp.	X	X	X	X	X	X
Glyptotendipes sensilus		X	X			
Kiefferulus sp.	X					
Metriocnemus sp.	X		X			
Microspectra sp.	X	X	X	X	X	X
Nanocladius sp.	X		X			
Orthocladius sp.	X	X	X	X	X	X
Parachironomus sp.		X			X	X
Paralauterborniella sp.						X
Pentaneurini		X			X	X
Polypedilum sp.	X	X	X	X	X	X
Potthastia longimanus	X	X				
Procladius sp.	X	X	X		X	X
Psectrocladius sp.	X	X	X	X	X	X
Psectrotanypus sp.			X	X	X	
Pseudochironomus sp.					X	X
Rheotanytarsus sp.	X	X	X	X	X	X

Table 10. (Continued)

	001	002	003	004	005	006
Smittia sp.	X	X				X
Stenochironomus sp.	X			X	X	
Stictochironomus sp.		X				
Tanypus sp.		X	X	X	X	X
Tribelos sp.	X		X		X	X
Trichocladius sp.	X	X	X		X	X
Trissocladius sp.			X		X	
Xenochironomus sp.	X			X		X
Family Empididae:						
Hemerodromia sp.					X	
Family Rhagionidae:						
Atherix variegata	X					
Family Simuliidae:						
Prosimulium sp.	X					X
Simulium sp.	X	X	X	X	X	X
Family Tipulidae:						
Antocha sp.	X	X	X	X	X	X
Helius sp.	X					
Tipula sp.	X					X
Family Stratiomyiidae:						
Stratiomyia sp.				X		
Family Culicidae:						
Chaoborus	X	X	X	X	X	X

Table 11. Checklist of macreinvertebrates common to all stations during pre-discharge survey.

Dugesia *sp.*

Aeolosoma *sp.*

Laevapex *fuseus*

Physa *sp.*

Corbicula *manilensis*

Sphaerium *sp.*

Gammarus *fasciatus*

Hetaerina *sp.*

Agrion *sp.*

Ishnura *sp.*

Neurocordulia *sp.*

Corydalus *cornutus*

Stenelmis *sp.*

Macronychus *glabratus*

Promoresia *sp.*

Baetis *sp.*

Tricorythodes *sp.*

Isonychia *sp.*

Stenonema *sp.*

Cheumatopsyche *sp.*

Hydropsyche *sp.*

Macronemum *sp.*

Agraylea *sp.*

Oecetis *sp.*

Neureclipsis *sp.*

Ablabesmyia *sp.*

Cricotopus *sp.*

Eukiefferiella *sp.*

Glyptotendipes *sp.*

Microspectra *sp.*

Orthocladius *sp.*

Polypedilum *sp.*

Psectrocladius *sp.*

Rheotanytarus *sp.*

Simulium *sp.*

Antocha *saxicola*

Table 12. Summary of mean numbers, kinds, biomass, diversity and redundnacy of macroinvertebrates collected from basket type artificial substrates at each station.

STATION	NUMBER OF SUBSTRATES	MEAN NO. MACROINVERTEBRATES PER BASKET	MEAN NO. OF KINDS PER BASKET	BIOMASS-(ASH-FREE WEIGHT, GRAMS)	MEAN DIVERSITY	MEAN REDUNDANCY
001	31	516	14.7	0.717	2.259	.3814
002	33	334.2	16.2	0.121	2.509	.3289
003	19	338.5	17.4	0.932	2.583	.3872
004	18	278	15.9	0.223	2.411	.3928
005	19	440.2	17.2	0.437	2.555	.3336
006	21	1056.3	16.6	0.198	2.671	.3164
TOTALS	141	489	16.6	0.438	2.498	.3567

Table 13. Summary of mean numbers, kinds biomass, diversity and redundancy collected by Hester-Dendy artificial substrates at each station.

STATION	NUMBER OF SUBSTRATES	MEAN NO. MACROINVERTEBRATES PER SAMPLER	MEAN NO. OF KINDS PER BASKET	BIOMASS-(ASH-FREE WEIGHT, GRAMS)	MEAN DIVERSITY	MEAN REDUNDANCY
001	2	87.5	14.5	.04465	2.398	.3586
002	3	86	15	.038	2.695	.2827
003	5	195.8	17.4	.088	2.386	.4837
004	1	189	21	.0295	2.919	.3559
005	9	231.8	13	.0446	2.222	.4175
006	6	524.17	14.17	.027	2.162	.4398
TOTALS	26	219.05	15.85	.0453	2.464	.3897

Table 14. Summary of mean numbers, kinds, biomass, diveristy and redundancy of microinvertebrates collected by Surber sampler at each station.

STATION	NUMBER OF SAMPLES	MEAN NO. MACROINVERTEBRATES PER SAMPLE	MEAN NO. OF KINDS PER BASKET	BIOMASS-(ASH-FREE WEIGHT, GRAMS	MEAN DIVERSITY	MEAN REDUNDANCY
001	4	137.25	12.75	.0468	2.166	.4596
002	2	334	10	.01	1.924	.4806
003	2	102.5	11.5	.05	2.066	.4578
004	3	54.3	10.67	.0092	2.270	.3155
005	3	596.67	15.3	.1815	2.100	.4925
006	2	249	19	.05	2.766	.3076
TOTALS	16	245.62	13.2	.058	2.215	.4189

Table 15. Relative importance (percent of total individuals collected) of the principal orders of macroinvertebrates collected by all methods within the study area (pre-discharge).

	STATIONS						
ORDERS	001	002	003	004	005	006	TOTAL
Diptera	5	9	5	8	8	11	8
Trichoptera	51	51	47	34	59	71	52
Ephemeroptera	8	5	8	24	11	11	11
Odonata	1	1	2	1	1	1	1
Gastropoda	3	5	9	6	2	0	4
Oligochaeta	22	13	13	13	10	2	12
Turbellaria	6	7	15	10	5	4	7

Table 16. Relative importance (percent of total individuals collected) of the principal orders of macroinvertebrates collected from basket substrate within study area, (pre-discharge).

	STATIONS						
Orders	001	002	003	004	005	006	TOTAL
Diptera	4	9	8	8	9	11	8
Trichoptera	51	52	41	33	61	73	52
Ephemeroptera	8	5	7	23	10	9	10
Odonata	1	1	2	1	1	0	1
Gastropoda	2	5	9	6	4	0	4
Oligochaeta	23	15	9	15	7	22	12
Turbellaria	7	7	16	10	6	4	8

Table 17. Relative importance (percent of total individuals collected) of the principal orders of macroinvertebrates collected by Hester-Dendy artificial substrates within the study area.

	STATIONS						
Orders	001	002	003	004	005	006	TOTAL
Diptera	8	2	3	19	6	10	8
Trichoptera	65	51	35	26	37	59	46
Ephemeroptera	15	3	3	53	19	27	20
Odonata	5	1	1	0	0	0	1
Gastropoda	2	12	15	2	2	0	6
Oligochaeta	2	16	11	0	5	2	6
Turbellaria	2	16	11	0	5	2	6

Table 18. Relative importance (percent of total individuals collected) of the principal orders of macroinvertebrates collected by Surber Sampler (1 ft ^{2}) within the study area.

	STATIONS						
Orders	001	002	003	004	005	006	TOTAL
Diptera	25	53	8	6	7	28	21
Trichoptera	47	46	66	74	74	55	60
Ephemeroptera	2	0	8	11	4	9	6
Odonata	0	0	0	0	0	1	0
Gastropoda	18	1	1	6	12	0	6
Oligochaeta	5	0	12	3	0	2	4
Turbellaria	1	0	2	0	1	2	1

Table 19. Macroinvertebrates collected by qualitative sampling and not by artificial substrates or surber sampler.

- Coleoptera
  - Hydrophilidae
    - *Tropesternus sp.*
  - Haliplidae
    - *Brychius sp.*
  - Dryopidae
    - *Lutrochus sp.*
- Odonata
  - Gomphidae
    - *Progomphus sp.*

Table 20. Results of Duncan's Multiple Range test comparing mean number of macroinvertebrates collected by H.D. artificial substrates at each station. Values* underscored by a common line do not differ at p.05 level.

STATION

001	002	003	004	005	006
88	86	196	189	232	524

Table 21. Results of Duncan's Multiple Range test comparing mean number of macroinvertebrate collected by Basket Artificial Substrate at each station. Values* underscored by a common line do not differ at p.05 level.

STATION

001	002	003	004	005	006
516	334	338	278	440	1056

Table 22. Results of Duncan's Multiple Range test comparing mean biomass(g) of macroinvertebrates collected by Basket Artificial Substrates at each station. Values* underscored by a common line do not differ at p.05 level.

STATION

001	002	003	004	005	006
0.0717	0.121	0.932	0.223	0.437	.198

*Values rounded to nearest whole number.

Table 23. Seasonal occurance of Macroinvertebrates collected from the James River from Riverville, Virginia downstream to Wingina, Virginia. March, 1974 through July, 1975.

	J	F	M	A	M	J	J	A	S	O	N	D
Phylum Platyhelminthes												
Class Turbellaria												
Order Tricladia												
Family Planariidae:			x				x		x	x		x
Cura foremanii			x	x		x	x	x	x	x	x	x
Curtisia sp.				x	x	x	x		x		x	
Hymanalla sp.						x						
Macrostomum sp.							x					
Dugesia sp.	x	x		x	x	x	x	x	x	x	x	x
Phagocata sp.					x	x	x					x
Phylum Annelida												
Class Hirudinea												
Order Pharynogobdellida												
Family Erpobdellidae:												
Erpobdella sp.		x										
Order Rhynchobdellida												
Family Glossiphoniidae:												
Actinobdella sp.										x		
Batracobdella sp.					x		x	x	x	x		
Helobdella sp.	x			x			x		x			
Marvinmeyeria lucidia												x
Placobdella sp.		x										
Class Oligochaeta												
Order Plesiopora												
Family Aeolosomatidae:												
Aeolosoma sp.	x	x	x	x	x	x	x		x	x		x
Family Enchytraeidae:			x									
Family Naididae:	x	x	x	x	x	x	x	x	x	x	x	x
Nais sp.				x	x	x	x					
Ophidonais serpentina				x								
Family Tubificidae:					x		x	x	x	x		
Branchiura sowerbyi						x				x	x	
Limnodrilus sp.												
Tubifex sp.			x	x			x			x		
Order Prospora												
Family Branchiobdellidae:			x		x							
Family Lumbriculidae:	x		x	x	x	x	x		x			
Order Opisthopora												
Family Lumbricidae:							x	x				
Phylum Molluska												
Class Gastropoda												
Order Basommatophora (Pulmonata)												
Family Ancylidae:												
Laevapex fuseus	x	x		x	x	x	x	x	x	x	x	x

Table 23. (Continued)

	J	F	M	A	M	J	J	A	S	O	N	D
Family Physidae:												
Physa sp.	x	x	x	x	x	x	x	x	x	x	x	x
Family Planorbidae:												
Gyralus sp.							x	x		x		
Helisoma sp.	x	x		x		x	x		x	x	x	
Family Lymnaeidae:												
Lymnaea sp.		x	x				x			x	x	
Order Mesogastropoda												
Family Hydrobiidae:												
Amnicola sp.			x	x	x	x	x		x	x	x	x
Hydrobia sp.							x			x		
Somatogyrus sp.												
Family Pleuroceridae:												
Goniobasis virginica					x		x		x	x	x	
Pleurocera sp.					x		x		x			
Spirodon carinata				x	x	x	x	x	x			
Family Valvatidae:												
Valvata sp.				x			x	x		x		
Valvata sincera					x							
Family Viviparidae:												
Viviparus sp.					x							
Compeloma sp.				x			x		x			
Class Pelecypoda												
Order Eulamellibranchia												
Family Unionidae:												
Elliptio sp.					x	x	x	x	x			
Order Heterodonata												
Family Sphaeriidae:												
Sphaerium sp.	x	x	x	x	x	x	x	x	x	x	x	x
Sphaerium striatinum				x	x		x	x				
Family corbiculidae												
Corbicula manilensis	x	x	x	x	x	x	x	x	x	x	x	x
Phylum Arthropoda												
Class Crustacea												
Order Amphipoda									x			
Family Gammaridae:												
Gammarus fasciatus		x	x	x	x	x	x		x	x		x
Family Hyalellidae:												
Hyalella azteca			x	x	x	x						x
Order Decapoda												
Family Astacidae:												
Cambarus sp.							x	x	x			
Orconectes sp.							x	x				
Order Isopoda												
Family Asellidae:												
Asellus sp.		x	x	x	x	x	x					x
Lircerus sp.	x			x								
Class Insecta												
Order Hemiptera												
Family Gerridae:												
Rheumatobates rileyi						x		x				

Table 23. (Continued)

	J	F	M	A	M	J	J	A	S	O	N	D
Order Lepidoptera												
Family Pyralididae:												
Eliophilia sp.			x	x								
Parargyractis sp.	x								x		x	
Order Odonata												
Family Aeshnidae:												
Aeshna sp.							x					
Anax sp.						x						
Boyeria sp.					x			x				
Epiaeschna heros		x										
Family Agrionidae:												
Agrion sp.			x		x	x	x					
Hetaerina sp.				x	x	x	x	x	x	x	x	
Family Coenagrionidae:												
Argia sp.				x	x	x	x	x	x	x		
Coenagrion sp.					x							
Ishnura sp.	x		x		x	x	x	x	x	x	x	
Nehallenia sp.		x			x	x	x	x	x	x	x	x
Lestes sp.							x					
Enallagma sp.							x					
Teleallagma daecki					x							
Family Gomphidae:												
Dromogomphus sp.				x								
Gomphus sp.					x							
Hagenius brevistylus				x	x		x	x	x		x	
Lanthus sp.		x	x			x	x					x
Progomphus sp.						x						
Family Libelludidae:												
Helocordulia sp.							x					
Epicordulia sp.								x		x		
Amphiagrion saucium						x						
Libellula sp.											x	
Macromia sp.		x	x	x	x	x	x		x	x		
Nannothemis bella					x							
Neurocordulia sp.				x	x		x	x	x			x
Trapezostigma sp.						x						
Family Petaluridae:												
Tachopteryx thoreyi					x		x					
Order Megaloptera												
Family Corydalidae:												
Chauliodes sp.								x		x	x	
Corydalus cornutus			x	x	x	x	x	x	x	x	x	x
Family Sialidae:												
Sialis sp.												
Order Coleoptera												
Family Elimdae:												
Ancyronyx variegata					x	x	x	x	x			
Stenelmis sp.		x		x	x	x	x	x	x			
Microcylloepus sp.				x	x							
Macronychus glabratus			x	x	x	x	x	x	x	x		
Dubiraphia sp.						x	x					
Promoresia sp.				x	x	x			x			
Oulimnius latiusculus				x	x							
Optiosevus sp.					x							

Table 23. (Continued)

	J	F	M	A	M	J	J	A	S	O	N	D
Family Dryopidae:												
Helichus sp.							x	x				
Lutrochus sp.							x					
Family Dytiscidae:												
Laccophilus sp.			x									
Family Haliplidae:												
Brychius sp.								X				
Family Hydrophilidae:												
Helochares sp.						x						
Berosus sp.				x	x				x			
Tropisternus sp.								X				
Family Gryinidae:												
Dineutus sp.						x						
Family Psephenidae:												
Ectopria nervosa				x								
Psephnus sp.				x		x			x			x
Family Ptilodactylidae:												
Anchytarsus sp.				x		x						
Order Plecoptera												
Family Nemouridae:												
Nemoura sp.			x	x								
Family Taeniopterygidae:												
Taeniopteryx sp.	x	x						x			x	x
Family Peltoperlidae:												
Peltoperla sp.				x	x			x				
Family Perlidae:												
Acroneuria sp.							x					
Perlesta sp.			x	x	x				x			
Family Perlodidae:												
Isoperla sp.			x	x								x
Order Ephemeroptera												
Family Baetidae:												
Baetis sp.				x	x	x	x	x	x	x		x
Pseudocloeon sp.					x	x	x			x		
Family Siphlonuridae:												
Isonychia sp.				x	x	x	x	x	x	x		
Family Tricorythidae:												
Tricorythodes sp.					x	x	x	x	x	x	x	
Family Caenidae:												
Brachycerus sp.							x					
Caenis sp.					x			x		x		
Family Ephemerellidae:												
Ephemerella Sp.				x	x	x	x					
Family Heptageniidae:												
Heptagenia sp.				x								
Stenonema sp.	x	x	x	x	x	x	x	x	x	x	x	x
Order Trichoptera												
Family Hydropsychidae:												
Cheumatopsyche sp.	x	x	x	x	x	x	x	x	x	x	x	x
Hydropsyche sp.	x	x	x	x	x	x	x	x	x	x	x	x
Macronemum sp.	x	x		x	x	x	x	x	x	x	x	x
Family Hydroptilidae:												
Agraylea sp.	x	x	x			x	x		x	x	x	x
Hydroptila sp.										x		x
Family Leptoceridae:												
Leptocerus sp.					X		x		x			

Table 23. (Continued)

	J	F	M	A	M	J	J	A	S	O	N	D
Leptocella sp.							x		x			
Leptocella candida					x							
Oecetis sp.	x			x	x	x	x	x	x	x	x	x
Family Molannidae:												
Molanna sp.				x				x				
Family Philoptamidae:												
Chimarra Sp.									x		x	
Wormaldia sp.						x						
Family Psychomyiidae:												
Neureclipsis sp.	x	x	x	x	x	x	x	x	x	x	x	x
Polycentropus sp.		x	x		x						x	
Psychomyia sp.							x					
Order Diptera												
Family Anthomyiidae:												
Limnophera sp.							x					
Family Chironomidae:												
Ablabesmyia sp.		x	x	x	x	x	x	x	x	x	x	x
Brillia sp.	x		x	x		x					x	
Cardiocladius sp.			x	x		x						
Chironomus sp.			x		x		x					
Coelotanypus sp.				x								
Constempellina sp.							x					
Cricotopus sp.	x	x	x	x	x	x	x	x	x	x	x	x
Cryptochironomus sp.			x		x	x		x				
Diamesa sp.			x	x	x					x		
Dicrotendipes sp.		x	x	x	x		x	x	x	x	x	x
Dicrotendipes modestus					x	x	x		x	x		
Dicrotendipes nervosus			x									
Diplocladius sp.			x	x		x	x					x
Einfeldia sp.				x	x			x				x
Endochironomus sp.	x	x		x	x		x		x		x	x
Eukiefferiella sp.	x	x		x	x	x	x	x	x	x	x	x
Glyptotendipes sp.	x	x	x	x				x	x	x	x	x
Glyptotendipes sensilus										x		
Kiefferulus sp.							x					
Metriocnemus sp.				x								
Microspectra sp.			x	x	x	x	x	x				
Nanocladius sp.				x								
Orthocladius sp.	x	x	x	x	x	x				x	x	x
Parachironomus sp.				x	x	x	x					
Paralauterborniella sp.				x		x						
Pentaneurini				x				x				
Polypedilum sp.			x	x	x	x	x	x	x	x		
Potthastia longimanus			x	x	x			x				
Procladius sp.			x	x	x	x	x	x	x	x	x	
Psectrocladius sp.	x		x	x	x	x	x	x	x	x		
Psectrotanypus sp.				x	x							
Pseudochironomus sp.					x	x		x				
Rheotanytarsus sp.	x		x	x	x	x	x	x	x			

Table 23. (Continued)

	J	F	M	A	M	J	J	A	S	O	N	D
Smittia sp.			x	x	x					x		
Stenochironomus sp.				x			x					
Stictochironomus sp.						x						
Tanypus sp.				x	x						x	
Tribelos sp.				x	x		x		x			
Trichocladius sp.	x	x	x	x		x		x		x		x
Trissocladius sp.				x								
Xenochironomus sp.					x		x	x	x			
Family Empididae:												
Hemerodromia sp.				x			x					
Family Rhagionidae:												
Atherix variegata				x			x					
Family Simuliidae:												
Prosimulium sp.		x		x								
Simulium sp.	x	x	x	x	x	x	x	x	x	x	x	x
Family Tipulidae:												
Antocha sp.				x	x	x	x		x	x	x	x
Helius sp.							x					
Tipula sp.				x	x							
Family Stratiomyiidae:												
Stratiomyia sp.				x								
Family Culicidae:												
Chaoborus	x	x	x	x	x	x	x	x	x	x	x	x

Table 24. Seasonal occurance (percent of total individuals collected) of the various orders of macro-invertebrates collected from the James River in the vicinity of Riverville, Virginia.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Diptera	23	11	19	21	21	13	4	1	8.5	1	4	15
Trichoptera	24	49	12.5	39	34	78	63	59	45	71	77	45
Plecoptera	11	0.4	0.8	0.5	1	0	0.01	0.02	0.01	0	0.1	1
Ephemeroptera	4	4	4.3	8	3	4	12	24	20	15	6	6
Odonata	0.2	2	0.3	0.4	2	0.3	1	0.5	1	0.3	0.3	0.5
Coleoptera	0	0.5	0.2	0.7	1	0.4	0.2	0.1	0.6	0.07	0	0.3
Crustacea	0.5	1.6	0.6	0.4	0.4	0.1	0.2	0.03	0.06	0.01	0	0.6
Molluska	3.1	4	0.3	1	8	1	8	2	6	2	9	18
Oligochaeta	32	28	61	27	25	0.3	0.5	1	8	3	1	3
Turbellaria	1.5	0.5	0.2	1	4	3	12	12	10	6	3	11
Total number of Organisms	410	789	1279	5650	5700	17,203	10,880	10,812	9655	9380	6025	1040
Number of Samples	4	5	8	24	24	17	29	13	24	17	9	9

Table 25. Season variation in mean number of organisms, mean number of kinds, mean biomass, mean diversity, $\overline{d}$, and redundancy/sample for all macroinvertebrate samples collected from the James River in the vicinity of Riverville, Virginia. March, 1974 through July, 1975.

MONTH	NO. OF SAMPLES	$\overline{X}$ NO. OF ORGANISMS	$\overline{X}$ NO. OF KINDS	$\overline{X}$ BIOMASS (ASH-FREE WT., GRAM)	$\overline{X}$ $\overline{d}$	$\overline{X}$ R	$\overline{X}$ TEMP. ^{o}C
January	4	103	12.25	.0119	2.153	.3632	4.7
February	5	158	12.6	.0387	2.438	.2744	6.4
March	8	186	12.7	.0116	2.015	.5232	9.2
April	24	378	16.83	.0473	2.364	.4154	14.4
May	24	233	17	.2358	2.602	.3442	19.4
June	17	1012	17.23	.2456	2.309	.4369	23.8
July	29	367	17.3	.2047	2.568	.3753	26.5
August	13	847	15.36	.1307	2.297	.4286	26.4
September	24	404	15.17	.2326	2.449	.3711	21.4
October	17	467	14.76	.2018	2.392	.3876	14.9
November	9	738	15.75	.1069	2.428	.3685	10.9
December	9	120	13.3	.0314	2.820	.2217	4.3

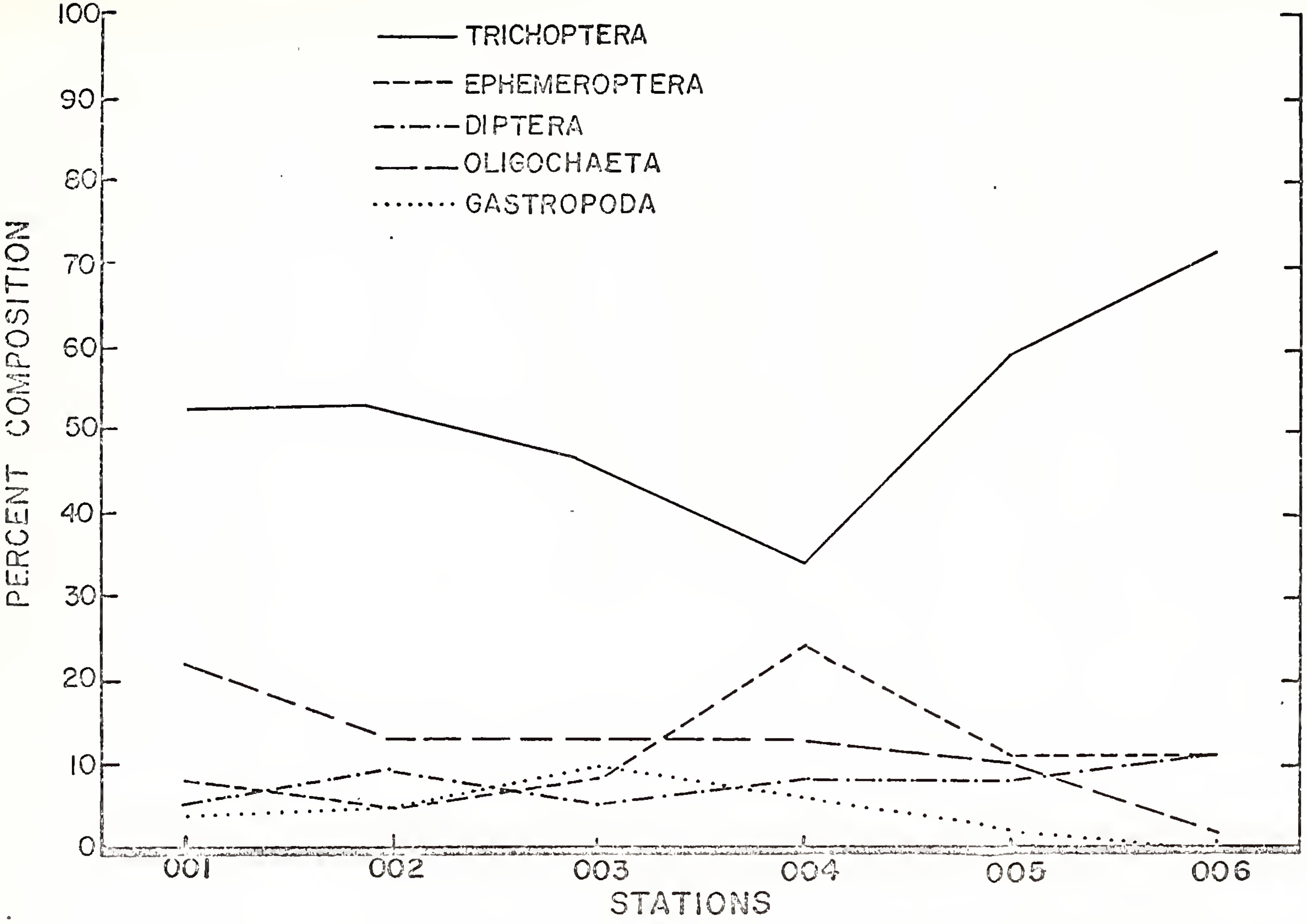


Figure 27. Percent composition of the principal macroinvertebrates collected from the James River in the vicinity of Riverville, Virginia.

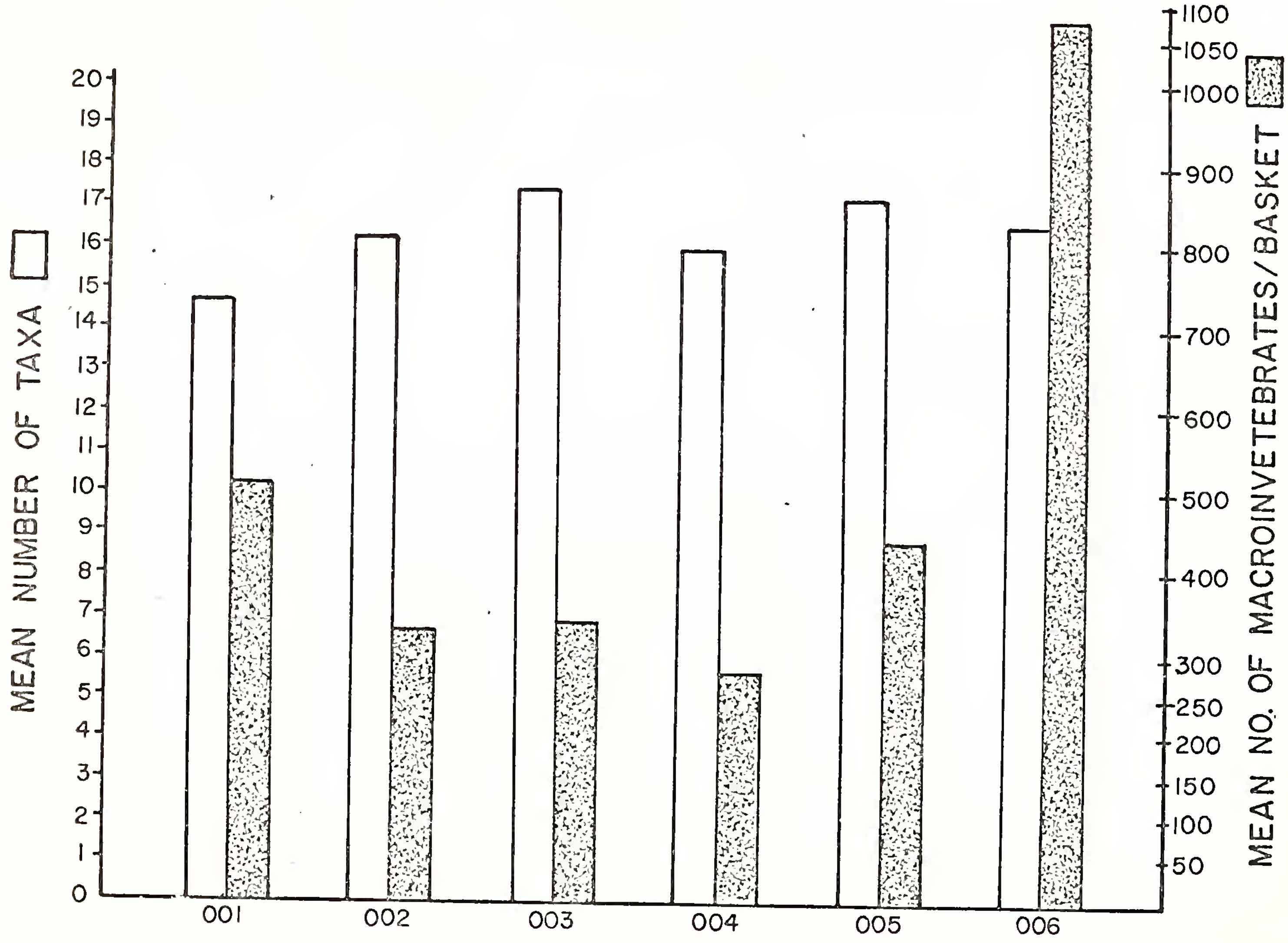


Figure 28. Mean number of macroinvertebrate taxa and mean number of specimens/basket sampler at each station.

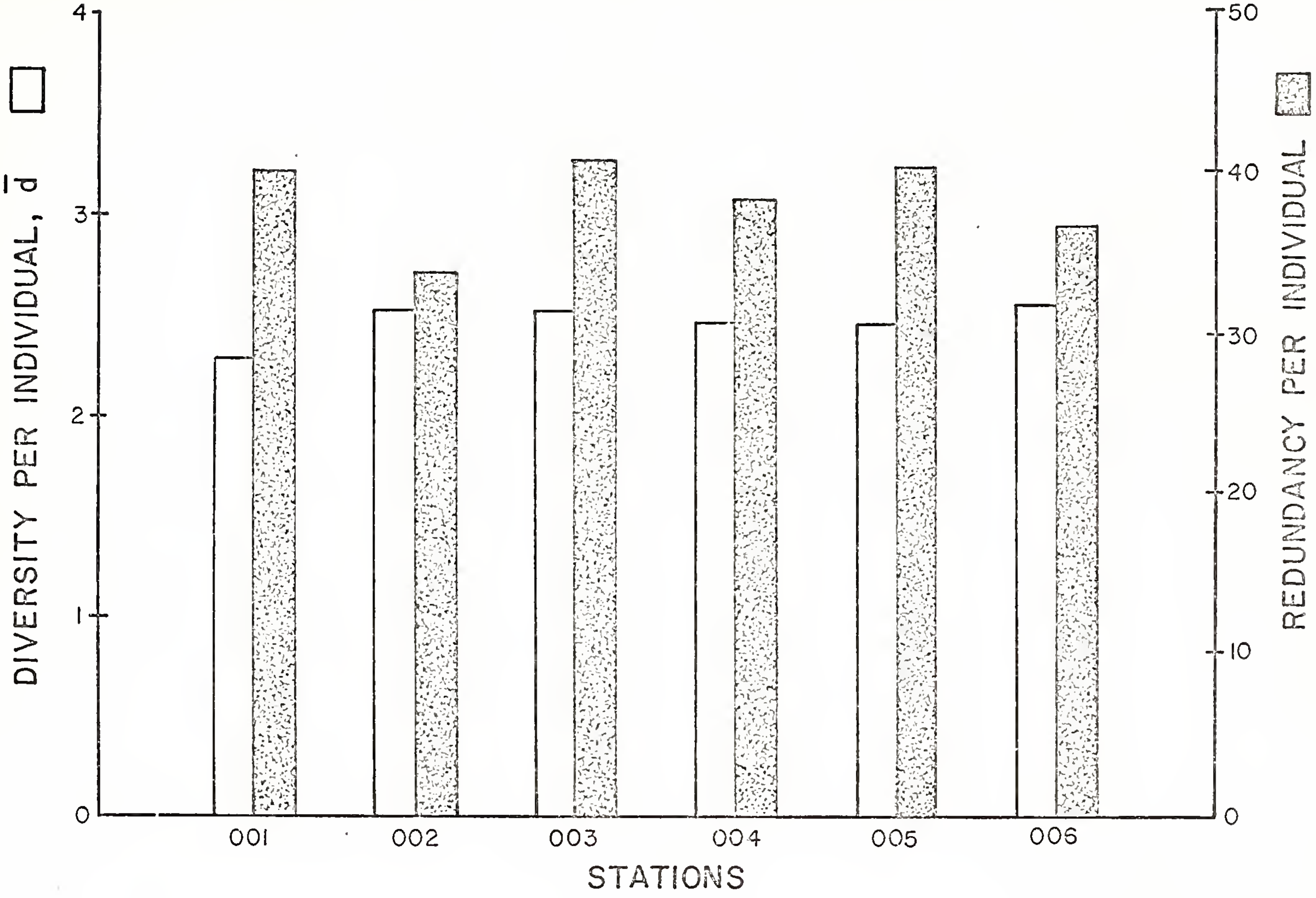


Figure 29. Mean diversity per individual, $\overline{d}$, and mean redundancy of all macroinvertebrate samples collected at each station.

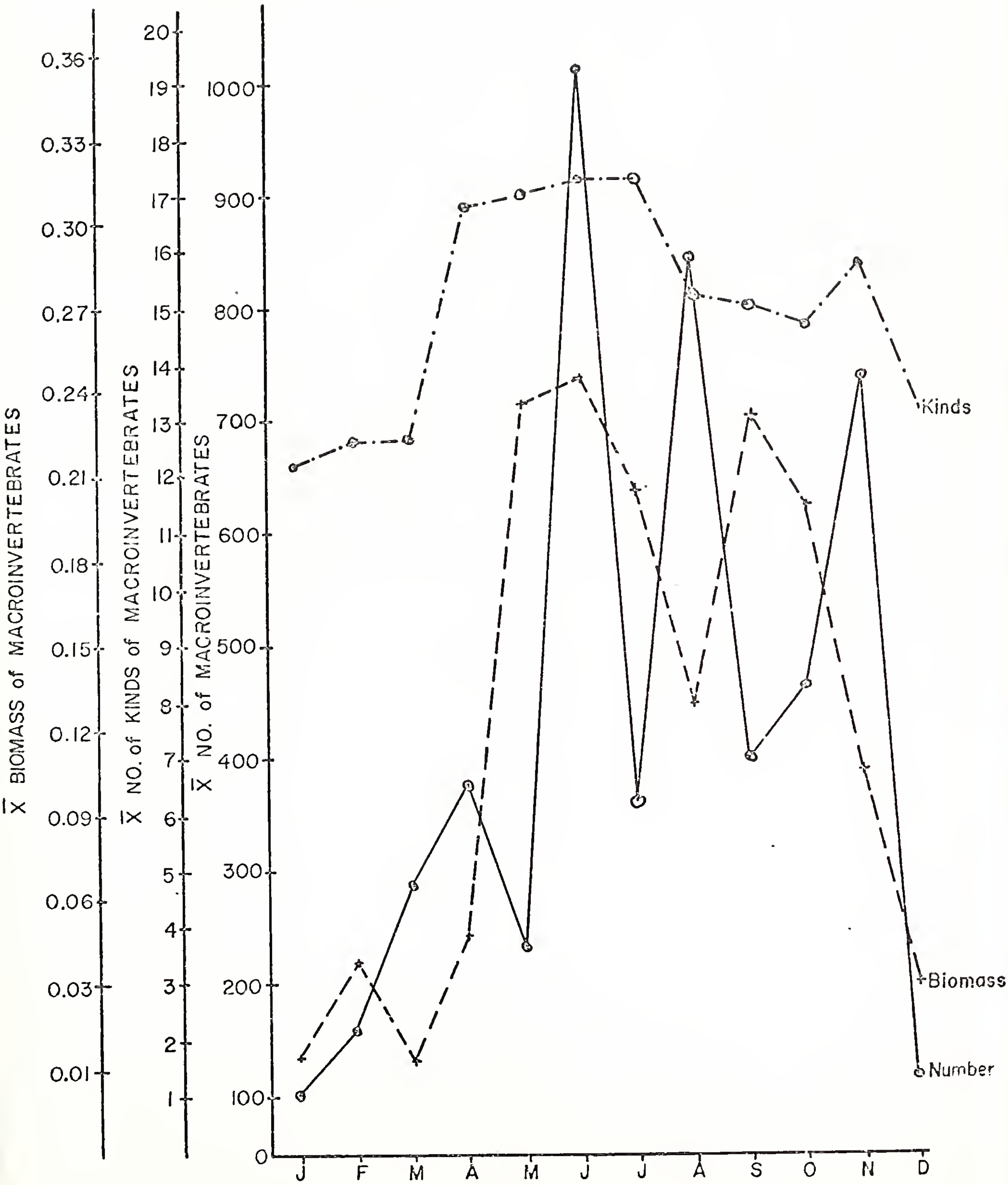


Figure 30. Mean numbers (—), mean number of kinds (-•-) and mean biomass (- -) of benthic macroinvertebrates collected seasonally by all methods.